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ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT

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AGARD CONFERENCE PROCEEDINGS 517

Helmet Mounted Displays and Night Vision Goggles

(Visuels Montés sur le Casque et Equipements de Vision Nocturne)

Papers presented at the Aerospace Medical Panel Symposium held in Pensacola, Florida, United States, 2nd May 1991.

NORTH ATLANTIC TREATY ORGANIZATION

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Preface

Papers covered basic and applied issues related to human factors and device integration. Three papers considered the ergonomics of helmet design and the snugness of fit to the head and the integration of new helmet mounted devices with existing equipment. Two papers considered the effects of novel helmet designs on the pilot's ability to control head position and avoid fatigue. Two papers reported in-flight testing of human performance using novel devices. Several other papers considered the human factors of visual performance related to such topics as degree of binocular overlap, overall field of view, and ability to maintain level flight. Other papers considered issues of the nature of information displayed, including data fused from multiple sources and design of abstract symbologies that present parameters of flight. A copy of the program is available from AGARD. Copies of papers presented are available from their authors, identified in that program.

Préface

Les communications couvrent des questions de base et des applications en ce qui concerne l'intégration des aides au pilotage et les facteurs humains. Trois communications examinent l'ergonomie de la conception des casques, l'ajustement des casques et l'intégration des nouveaux dispositifs montés sur le casque aux équipements existants. Deux communications portent sur les effets des nouveaux casques sur la possibilité pour le pilote de décider de la position de sa tête et d'éviter la fatigue. Deux autres communications concernent le contrôle des performances humaines en vol à l'aide de nouveaux dispositifs. D'autres communications rendent compte des facteurs humains dans les performances visuelles par le biais de questions telles que le degré de chevauchement binoculaire, le champ de vision global et la capacité de maintenir le vol horizontal. D'autres communications encore, examinent la nature des informations affichées, y compris des données fusionnées, de sources multiples, et la conception de symbologie abstraites représentant des paramètres de vol. Le programme du symposium vous sera transmis par l'AGARD sur simple demande. Des exemplaires des communications présentées sont disponibles chez les auteurs aux adresses indiquées dans le programme.

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Tel: 33(1) 47 38 57 60
Telex: 610176 (France)
Telefax: 33(1) 47 38 57 99

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* Abstract only.

FIXED WING NIGHT ATTACK

EO INTEGRATION AND SENSOR FUSION

Mr Les Evans, BSc, MRAeS, MSETP
IBIS Aerosystems Ltd
3, Colworth Road - Sharnbrook, Bedford MK44 1ET - U.K.

Summary

The introduction of NVGs and FLIR into fast jet aircraft has not been achieved without some problems being encountered. Amongst these problems some in particular relate to the integration between the NVGs and the FLIR image as projected onto the head up display, and these are addressed here. It was found that when the pilot was presented with two images of the outside scene produced by sensors operating at different wavelengths he could find the resulting combination of images to be very hard to comprehend. This problem of "Sensor Fusion" was most noticeable where folded-optics NVGs were used, and it was overcome by causing the NVGs to be switched off automatically when they were pointed at the HUD. Problems of sensor fusion were not normally encountered when straight-through NVGs were used. Other integration problems encountered were those of ensuring that HUD symbology was given sufficient contrast relative to the FLIR video, and that the relative brilliance of the HUD symbology was easily controlled by the pilot. Some particular aspects of NVG use in fast-jet aircraft are discussed. It was found that helmet fit had to be tight to ensure that the high helmet-rotational forces produced by normal accellerations were contained, and also that when wearing NVGs whilst pulling "g" a tumbling sensation could be induced in the pilot by head movements.

Introduction

1. I am going to talk about some of the aeromedical aspects of the development of fixed wing night attack using electro-optic sensors. In particular, I shall address some of the problems encountered when Night Vision Goggles and Forward Looking Infra- Red equipments were integrated into a complete airborne system, and I shall address some of the aeromedical problems encountered when NVGs were used in fast jet aircraft.

2. My knowledge of these problems stems from my experience with the Royal Aerospace Establishments at Farnborough and Bedford, and with the Royal Air Force's Central Tactics and Trials Organisation at Boscombe Down. Throughout this time I have been privileged to belong to teams developing the use of NVGs and FLIR on a two-seat Harrier aircraft as well as on a Buccaneer and a two-seat Jaguar. I have also been fortunate enough to have been involved remotely in the US Marine Corps AV-8B programme and another more recent similar programme.

Aircraft Installations

3. Typically, the aircraft installation utilised in these programmes had a nose-mounted FLIR sensor with a fixed field of view and a fixed 1-to-1 magnification. The image produced was displayed on a head up display producing, in theory, real world correlation over a field of view of about 24 degrees in azimuth by about 18 degrees in the vertical. A second, head down display was also provided for daytime use. The FLIR equipment used on all of these programmes was the GEC TICM II, in various stages of development.

4. The NVGs used in these programmes were always helmet-mounted, either ANVIS Gen III in the case of the UK, or GEC Cat's Eyes in the case of the US Marine Corps. The field of view of the ANVIS NVGs was about 40 degrees and that of the Cat's Eyes was a little less. In both cases the NVGs could be removed manually if required, but they were normally worn and switched on throughout the complete sortie. In the UK a facility was also provided which would detach the NVGs automatically from the helmet in the event of an ejection. The head up displays used in these programmes were of the reflective optics type utilising a dual combiner display glass.

Concept of Operation

5. That then describes the basic equipment used in the programmes in which I was involved, but what was the general concept of operation? Well it was recognised that the performance of NVGs and FLIR were affected

by different factors; NVGs were dependent on reasonable light levels whereas good FLIR performance required good thermal conditions and, in particular, low levels of humidity in the atmosphere. Thus the provision of both would enable operations to continue under a wide range of conditions. Perhaps more significant, however, was the fact that the FLIR field of view was fixed to the aircraft centreline and that the pilot could not see into turns using it. Unlike the F-16 and F-15, we did not have terrain-following radar and so terrain clearance at low level was dependant on visual references. The use of NVGs allowed us to retain those visual references whilst turning, giving considerable freedom of manoeuvre at low level.

6. In our concept then, the pilot used his NVGs at all times and, in the earlier development flying, he always viewed the FLIR image through the NVGs. Later, using different NVG technology as we shall see, the pilot was enabled to view the FLIR directly. Head up display symbology was provided as normal, superimposed onto the FLIR image.

7. Thus the pilot would fly principally by reference to the NVG images, backed up by the FLIR image when that was better. He would quite frequently reject the FLIR image from the HUD when the thermal conditions were poor, but would always retain the NVG image. When acquiring tactical targets we normally used the FLIR because the high thermal contrast of these targets made them very conspicuous on that display.

8. That, then, was a brief description of our equipments and of our mode of operation. What did we learn about the use of EO sensors which might be of interest to this body today? There are three areas of potential interest which I will cover; the use of NVGs in a fast jet; displaying symbology on top of a FLIR video; and sensor fusion.

NVGs in the Fast-Jet

9. Let's consider the use of NVGs in the fast jet environment. There is much which could be said on this subject but I will just mention a couple of points. As many of you will know, the use of NVGs for low flying in a fast jet aircraft imposes a significant workload on the pilot. This is because the image resolution is naturally poorer than that of normal daylight flying and because the NVG field of view is restricted. The major impact of this was that the pilot's depth perception was significantly reduced and his ability to estimate terrain clearance could be poor, particularly where there was little texture in the scene and the light levels were low. We found as a result, that a good, intuitive presentation of height in the HUD was essential for safe operations at low level, and by this we meant the use of an analogue display of height as opposed to a digital display.

10. Another facet of NVG operations which quickly came to light was that the helmets had to be made to fit well and to resist the large forwards rotational moment caused by the NVGs when "g" was being applied. It can be quite disconcerting when pulling around a hill at low level if all you can see through the NVGs is the top of the control column! We found initially with our Mk4A helmets that in order to achieve the required rotational restraint the helmet had to be tightened so much as to make it very uncomfortable to wear. This problem was addressed and we found that the Mk4B, which had a front strap, was easier to restrain. Nonetheless, it required constant effort to ensure that our helmets remained well fitted despite constant use.

11. On the subject of the use of NVGs under high g, I can add that we were able to use operational levels of normal acceleration without too much difficulty. Normal turns at 3 to 4g presented no problem once the pilot had learnt to anticipate the strain on the neck muscles, and 6g was sustainable for short periods. We did notice, however, that there was a big difference between the task of locking the head in one place under g, and that of moving the head about once the g had been applied. For example, when turning and looking into the turn, it was found to be much easier to glance down under the NVGs at the HUD than to allow the head to rotate downwards to look at the HUD through the NVGs. If the pilot did move the head then it could cause him to feel a strange "tumbling" sensation as he halted the movement. I do not know the reason for this, but I would suspect it was related to the fact that the pilot was making unusually high demands on his neck muscles and that the relationship between changes in the strain held by those muscles and the resulting head movement was an unusual one.

HUD Symbology and FLIR Video

12. On the next topic, that of the presentation of HUD symbology on the FLIR video, there are two integration aspects which are interesting; firstly, how does one achieve adequate contrast between the two, and secondly, how is the brilliance of the symbology to be controlled?

13. Achieving adequate contrast between the symbology and the FLIR can be difficult. As you can imagine, the cold sky will appear as bright white if the thermal imagery is presented as black-hot. Black hot was the prefered polarity for most of the time and so the problem of reading white symbology against the white sky was a recuring one. The problem is alleviated somewhat if the symbology is overwritten onto the FLIR video using cursive techniques in video flyback time. If this is done then the symbology can be made to appear very bright and very crisp in comparison to the FLIR video, and it can be read even against a moderately bright white sky. However, not all display systems had sufficient flyback time available to allow the complete symbology suite to be written within it, and so it was common practice to write the symbology in raster format inter-leaved with the video. In this case it was hard to achieve good contrast with the FLIR video and it was necessary to resort to the use of a thin black border around the individual symbols to allow them to be seen against the white sky. The result was an adequate degree of contrast on a picture which, however, did not look quite as neat as that produced by the use of cursive symbology.

14. The other aspect of HUD symbology which I mentioned was that concerning the control of the symbology brilliance relative to that of the video. Most systems which we assessed allowed the relative symbology brilliance to be controlled by the pilot but not all did, and not all controls were easy to use. For example, one of our earlier systems required the pilot to enter the required relative brilliance as a number between 1 and 8 via a menu-driven programme on the up-front controller. As you can imagine, this was not easily accomplished at 300ft and 420kts at night. Unfortunately, the pilot does have a requirement to modulate the symbology relative brilliance routinely in flight as the nature of the video background changes, and we found it to be very important to provide him with an analogue controller for this.

Sensor Fusion

15. I would like to move on now to the subject of sensor fusion. This was a problem which only became apparent at a late stage in our work when we looked at a different NVG technology. In order to understand the problem of sensor fusion as we saw it, it is necessary that one understands the nature of the two images which are presented to the pilot. So, if you will excuss me, I will spend a couple of minutes discussing these.

16. The NVG image, as you will know, is an amplified light image responsive to the visual and near-IR regions and with a gain of about 30,000. The image so produced varies in character enormously depending on the amount of ambient light, on the texture in the scene and on the amount of shadowing in the scene, amongst other factors. The image is produced in a blueish-green colour and is usually quite grainy, the resolution diminishing as the light level drops. Furthermore, in very low light levels the picture will suffer from scintillation, which is characterised by the continual appearance and disappearance of small pin-pricks of light, like snow flakes.

17. It is important to note, though, that the image produced by the NVGs is of reflected light and that the image is very similar in construction to that which we are all used to in our daily lives. Objects are of familiar shapes, the distribution of optical contrast in the scene is almost normal, and shadows appear where we expect them to be. The problems experienced by pilots in using NVGs for low level navigation have related to the poor resolution, the lack of depth perception and the limited field of view. However, the interpretation of the image has not been a problem.

18. The image produced by the FLIR is, of course, quite different from that produced by the NVGs. The wavelength band utilised, 8-13 microns, is well removed from that of light, and it is thermal contrast rather than optical contrast which creates the image. Thus the image quality is quite independant of light levels and, instead, the amount of thermal contrast in the scene, together with the amount of moisture in the atmosphere,

become dominant factors. Picture quality or resolution can be quite good, but it can also be very variable even over short periods of time. Pilots generally adapted quite quickly to the use of a thermal image, although it was found that the provision of some good instruction before-hand could greatly increase the effectiveness of their flying training. Prominant features in the thermal image are often very different from those of the visual scene and they look very different. Cold lakes and rivers are jet black or bright white (depending on the polarity used), and concrete strips can also stand out very clearly if they have been subjected to significant heating or cooling. So, although low level flight by the use of NVGs and FLIR was found to involve a high workload on the pilot, it was also found that he could interpret either image reasonably intuitively.

19. The problem of sensor fusion was noticed when the pilot was asked to view the NVG image and the FLIR image overlaid on each other. With straight-through NVGs there really did not seem to be a problem: it was the introduction of folded optics NVGs which brought the problem to our attention. I should perhaps explain briefly the difference between straight-through and folded optics NVGs.

20. Straight-through NVGs, such as ANVIS, place the intensifier tubes directly in front of the pilot's eyes and he is required to view both the outside scene and the HUD FLIR image through the intensifiers. The HUD output must be filtered such that it does not cause the NVGs to be dazzled, but at the same time the HUD image must be detectable by them.

21. Folded-optics NVGs such as Cat's Eyes, on the other hand, place the intensifier tubes above the pilot's direct line of sight, and then bring the images down to his eye level through combiner lenses. The pilot views the outside scene via the intensifier tubes but he views the HUD FLIR image directly through the combiner lenses. The HUD output must be filtered so that it is totally invisible to the NVGs and yet it must remain visible to the naked eye. Folded optics NVGs have the advantage that they allow the FLIR image to be viewed directly, thus avoiding a certain amount of resolution loss which occurs when the FLIR image is viewed through intensifier tubes. They also allow easier viewing of the cockpit under the NVGs. However, their use did throw up the problem of sensor fusion.

22. It was found with folded optics NVGs that when the pilot viewed the FLIR image and the NVG image together, he very often found the resulting combined image to be confusing. At first it was thought that the problem was simply that real world correlation of the FLIR image had not been achieved. However, we soon proved this not to be the case. I believe that the problem lay in the pilot's inability to interpret two similar but not identical images superimposed one on the other. The images were produced from sensors operating at very different wavelengths, producing images of the scene which were often quite different. These images were presented to the pilot in different colours: the HUD FLIR was bright green whereas the NVG image was a dull blueish-green. Also, the images were both presented at a high brightness level, competing for attention, and, finally, they were focused at different distances from the pilot's eyes.

23. As a result, the pilots found it quite disturbing to view both the NVG and FLIR images simultaneously when using folded-optics NVGs and a solution to this problem was required. We shall see soon how this was achieved.

24. But why was this sensor fusion problem not detected when straight-through NVGs were used? For indeed there had been few complaints from the pilots about the mixing of images. The answer, I believe, lies in three parts. Firstly, and perhaps most importantly, the NVGs tended to gain-down to a certain extent in response to the light output from the HUD, even though that output was filtered to avoid dazzling the NVGs. Thus it was that only on very bright nights when the NVG image was dominant would the pilot be able to see more than a dim image of the scene beyond the HUD if the FLIR was being displayed there. Thus the battle for dominance between the two images had been fought inside the intensifier tubes before an image was presented to the pilot. Secondly, the two images, FLIR and NVG, were presented to the pilot in one colour, that of the NVG image. Finally, the two images were presented to the pilot at one focal length. In effect, then, the two images had been converted into one by the NVGs.

25. So what was the solution to the sensor fusion problem noticed with folded optics NVGs? Quite simply the NVGs were caused to switch off automatically when the pilot looked towards the HUD, and were switched on again when he looked away from it. In order to achieve this, an IR source was mounted near the HUD pointing towards the pilot and a very directional IR detector was mounted on the NVGs, boresighted to the NVGs centreline. Whenever the detector sensed the IR radiation emanating from the HUD-mounted source, it sent a signal to the NVG circuits de-powering them. This was not as easy to implement as it might sound, but nonetheless it was eventually made to work successfully.

26. There has been considerable debate over which type of NVG is better suited to integrate with a head up display of FLIR; straight through or folded optics. I do not intend to indicate a preference either way; they are both useable with their own advantages. I would ask though, what lessons we should learn about sensor fusion for the next generation of EO devices, integrated helmet-mounted displays of thermal and low light images. We shall have to be very careful indeed that the images are presented to the pilot in a manner which will allow him to comprehend them both together. This may mean, and I stress it may mean, that the images presented to the pilot should finally derive from only one image generator, even though they might have originated from seperate sensors. Alternatively, it may be found to be preferable to provide the pilot with a throttle-mounted switch with which he can select the sensor of his choice. But we should not take lightly the potential problems of sensor fusion, especially when we are adding more and more sources of information simultaneously to the display presented to the pilot.

THE DESIGN AND EVALUATION OF FAST-JET HELMET MOUNTED DISPLAYS

by

A. Karavis
G.J.N Clarkson

Flight Systems Department
Royal Aerospace Establishment
Farnborough, Hampshire, GU14 6TD, United Kingdom

SUMMARY

The design philosophy adopted by the Flight Systems Department of the Royal Aerospace Establishment, Farnborough for its fast-jet helmet display programme is described. Details are given of the development of two devices and the tests and methods used to meet the flight safety measurements.

The devices, a Helmet Mounted Sight (HMS) and an Oxygen Mask Mounted Sight (OMMS), each posed different problems due to their inherently dissimilar concepts. Modifications to the devices as a result of ground and air testing to meet flight safety and operational requirements are covered. The ergonomic considerations applicable to the use of these and other head mounted devices when employed as integral components of the weapon system are also discussed. In addition to describing the physical development of the devices, a brief account is given of the display design considerations.

The results of these activities have been embodied in the RAE flight test programme which has successfully produced two helmet devices for evaluation in a combat environment. The knowledge gained from this programme is discussed in the paper together with its relevance to the successful procurement of future helmet mounted devices for combat aircraft.

1 PROGRAMME PHILOSOPHY

A significant amount of ground based research had been conducted at RAE Farnborough using the air combat simulator to evaluate a variety of operational applications of helmet mounted devices. In general, the slaving of an aircraft sensor or weapon seeker to the pilot's direction of regard proved to be of significant benefit[1,2].

Trials had also been conducted to study the physiological parameters affecting the pilot's ability to acquire targets under conditions of high 'g' and vibration whilst using such a device. The ability of a pilot to point his head in a particular direction within the restrictions of his usual cockpit impediments, *ie* life preserver, ejection seat head rest and harness, was also studied[3,4].

In the light of this ground based experience, the next logical step was an airborne evaluation. Not only would a flight trial programme confirm (or deny) the human factors findings and simulated mission results to date, but it would also force the team to address the real issues of designing a helmet mounted device for use in a fast-jet cockpit environment and qualifying it for ejection and crash safety.

The task undertaken was therefore two-fold; to procure a safe, workable helmet mounted aiming device and to obtain in-flight experience of a head slaved weapon aiming system.

Experience has shown that an incremental approach to system development is often the quickest route to success, especially where the human operator is involved. On this basis it was decided to develop a simple fixed reticle LED helmet mounted sight (HMS) and to use it in conjunction with a current in-service short range air to air missile system thereby replicating the system used in earlier ground based trials as illustrated in Fig 1. The operational scenario was therefore defined as close air to air combat engagement, although a brief assessment of the system in the air to ground role would also be made.

1.1 Specifications

Before an HMS could be developed, consideration was given to the performance envelope that was required. It was necessary that the device was physically and electrically compatible with the aircrew equipment assembly and must present no additional hazards to the aircrew during flight and emergency egress from the cockpit. In particular, any additional mass on the helmet had to be minimised and a design aim was set at 100 gms. Restrictions to pilot head mobility within the confines of the cockpit must also be minimised. It was desirable that it used an approved flying helmet to reduce the flight safety clearance programme to a minimum. The normal use of the clear visor and sun visor had to be retained as standard fast jet operating procedures require the pilot to fly with a visor down at all times. Flight throughout the whole aircraft operating envelope was not to be restricted in any way. The HMS was required to be compatible with cockpit displays and equipment and allow the standard cockpit procedures to be carried out.

The sight itself had to present minimum obscuration to the pilot and the symbols remain legible under the full range of daylight ambient illumination levels. The optical combiner was required to present minimal discolouration of the scene. Experience in the simulator trials indicated that a field of view of approximately 5° would be adequate to contain a simple weapon aiming format. Cockpit controls were required to be simple and logical.

The above represents a series of design aims from which a detailed build and performance specification was written.

1.2 Proposed solutions

An extra-mural research contract was placed for the development of a sight to be incorporated into an ALPHA helmet. This helmet type was selected as it was an approved item and was representative of a modern lightweight flying helmet. It was fitted with dual visors and was available in a range of five sizes to cater for aircrew

anthropometric variations. A detailed description of the Alpha Helmet Sight is given later in the paper and is illustrated in Fig 2.

Consideration was also given to possible alternative solutions. It was seen that as standard helmets were expensive to procure, the acquisition of HMS equipped helmets in a variety of sizes would become an even more costly activity. In addition, any requirement to retrofit a helmet mounted capability into an aircraft would result in all pilots being re-equipped with a new and expensive helmet. A concept which had had some attention, but seemingly not reached maturity, was that of fitting a sight to an oxygen mask. The RAF mask is available in two sizes and is thought to be one of the best in service, being comfortable and less leaky than most. It is considerably cheaper than a helmet and therefore presents an attractive alternative from a procurement point of view. If it is correctly adjusted it maintains a rigid and stable position relative to the pilot's head. However, any additional weight to the mask could be considered to be a disadvantage, having a long moment arm about the head c of g but this can be offset by its lower position on the head. Further to this, as the overall head assembly volume is increased, the device would need to be small.

It was considered a viable option to take at least to the working prototype stage. On this basis a small intra-mural development programme was undertaken utilising readily available collimating and combining optics. The Oxygen Mask Mounted Sight (OMMS) is described in detail in the next section and is shown in Fig 3.

1.3 Head tracker

In order to take advantage of the benefits of a HMS, the direction in which the pilot is looking must be available to the aircraft or weapon systems. This is achieved by means of a head position sensing system (HPS). Several companies market devices based upon a variety of technologies, such as electromagnetics, optics, and ultrasonics. Although an essential part of the overall system, and a critical item in determining system performance, the development of an HPS was not taken to be an aim of the programme. The previously mentioned simulator trials had made use of an electromagnetic system (Fig 4) which had proved to be reliable, was sufficiently accurate, and was considered to be a low risk element to the trial. In addition, it was considered that experience ought to stand us in good stead.

1.4 Test aircraft

The primary flight test vehicle available for the trials was a two seat Jaguar T Mk 2A illustrated in Fig 5. Although not the most agile of air combat aircraft, its flight envelope was sufficient for a thorough investigation of HMS weapon aiming. A tandem seater has obvious advantages for this type of research flying, and indeed is essential for full exploration of two crew operational benefits. To examine HMS performance under high 'g' condition some use was also made of a Hawk aircraft.

The Jaguar is capable of carrying Sidewinder air to air missiles on the outboard pylons and the missile fire control equipment was suitably modified so that the seekers could be driven from signals derived from the pilot's head position. The front and rear cockpits were equipped with the head tracker equipment.

In addition to a full digital recording system being fitted, one pylon was modified to accommodate an ACMI (Air Combat Manoeuvring Instrumentation) pod which enabled the aircraft combat related data to be transmitted in real time to the ground station when flying over an instrumented range. This data was also recorded for later quantitative evaluations. A miniature colour TV camera fitted with a wide angle lens was attached to the left of the HUD enabling in flight recording of pilot's activities to be made. Fig 6 shows a still frame from this CCTV system.

2 DEVELOPMENT AND FLIGHT SAFETY TESTING OF HELMET SIGHTS

2.1 Engineering considerations

Both the OMMS and the ALPHA helmet sights were designed specifically for use in fast-jets and, as mentioned previously, certain criteria were paramount if they were to be successful. These criteria involved low weight, an ejection safe design, compatibility with existing Aircrew Equipment Assemblies (AEA) and adequate ergonomics.

The effects of 'g' and the need to ensure good head mobility in the cockpit required that the weight of the helmet sights was as low as practicable. This would be achieved for the OMMS by the use of plastic and carbon fibre materials. The ALPHA helmet sight would also make use of plastics but the choice of the ALPHA aircrew helmet as a basis for the design contributed considerably.

The main flight safety issue that had to be addressed was ejection. It was decided that both helmet sights should be designed to allow safe ejection without removal of any of the sighting equipment. To verify the performance of the designs both helmets would be tested under air-blast together with some ejection tower and sled tests. AEA checks were also planned to ensure that any extra cabling did not affect the ejection sequence. Compatibility with existing AEA was important not only for ejection but also to ensure that cockpit mobility was unhindered and no fouling occurred with the controls.

Finally, the helmet sight designs would need to address ergonomic issues so that optimum performance could be gained from them in the fast-jet cockpit. This topic again emphasised the need fo good AEA integration as well as other optical aspects. This topic is considered in detail under section 3.0.

2.2 Development

2.2.1 Oxygen Mask-Mounted Sight

The OMMS was developed as an alternative to the conventional helmet-mounted sight concept. It offered several potential benefits particularly in overcoming aircrew equipment compatibility problems, potentially good ejection performance and sight stability.

Several designs of OMMS were produced before the flight version was produced. These earlier OMMS were used to investigate head mobility, performance under 'g' and simulator testing (Ref 5). The final flightworthy design added approximately 100 gms to the standard oxygen mask. It consisted of a small collimated LED display with a transparent combiner. This was fitted to the mask by means of a carbon fibre plate and full adjustment of the optical position of the sight display was provided. The optical design of the OMMS provided a large exit pupil and together with the stability afforded by the oxygen mask when fitted correctly ensured that the pilot would be able to see the display at all times. The head tracker sensor was also placed on the mask.

Once flight safety testing had been successfully completed (see section 2.3), flight trials were undertaken with the OMMS in Jaguar and Hawk fast-jets to assess its performance in isolation. The results of these sorties were encouraging and only minor changes were needed before the OMMS could be integrated with the full head pointing weapon system (section 4.1) for trials evaluation. However, it should be stated that there were several areas highlighted in the flight tests which would need to be improved in a developed version of the sight.

2.2.2 ALPHA Helmet-Mounted Sight (AHMS)

The ALPHA Helmet-Mounted Sight (AHMS) was designed to enable 'conventional' helmet sight to be evaluated. The choice of the ALPHA helmet as a basis for the design was a direct attempt to minimise the weight of the sight and provide a stable platform. A visor projection system was chosen in an attempt to reduce obstruction to the pilot's view.

Again the weight increase from the addition of the sight was kept to 100 gms approximately. The helmet profile was kept as standard as possible except for the addition of the head tracker sensor and a small extension of the visor arms. An electronics package was fitted inside the helmet together with the system wiring. Unlike the OMMS, the AHMS did not have a fully adjustable display but the exit pupil was designed to cater for the majority of wearers.

Having successfully been tested for flight (section 2.3), the AHMS was flown in isolation as per the OMMS sorties. Unfortunately, several deficiencies were found with the Mk 1 AHMS during these flights (section 4.1). The problems centred around the optical performance of the sight and, to correct these, the AHMS was modified to Mk 2 standard. The AHMS Mk 2 was retested and found to give good performance.

2.3 Ejection safety

As mentioned above, ejection safety was considered to be a prime requirement for the helmet sights developed for the programme. This criteria has often been the most difficult to satisfy for fast-jet helmet projects. Both the OMMS and the AHMS were designed for fast-jet use at the outset and representative mock-ups were produced for testing.

Air-blast tests were carried out at RAE Bedford for both devices. Each sight was exposed to air-blasts in various orientations and at various speeds up to 650 kn. The results of the tests were documented by high speed cameras and still photography. Figs 7 and 8 show the OMMS and AHMS mock-ups in the test rig. These results indicated that for both the OMMS and the ALPHA, injury was unlikely to occur up to 450 kn. Beyond this speed, known limitations with the head equipment assembly became apparent, although in certain orientations the helmets sights behaved acceptably at higher speeds.

The more unusual design of the OMMS required further ejection testing and this took the form of some ejection tower shots (Fig 9) plus a complete ejection from a rocket sled (Fig 10). The ejection tower tests examined the performance of the OMMS during the gun stroke phase of ejection. The results of the tests showed that the presence of the sensor on the mask actually had a beneficial effect in preventing the mask riding up the face. The complete ejection seat firing took place at 450 kn. No untoward effects were found and the sight remained in place throughout the ejection with no penetration of the visors occurring.

3 ERGONOMIC CONSIDERATIONS

In developing both sights, it was important that consideration was given at an early stage to the fundamental issue of ensuring that the pilot could operate the aircraft whilst wearing the device under the wide range of operating conditions that would be experienced. Also, his ability to use the device for the intended purpose was high on the list of requirements!

3.1 Brightness

The primary scenario in which the devices would initially be used was medium to high altitude close air combat, with a high probability of direct sunlight or extremely bright reflected sunlight from the cloud tops against which the sight reticle must be visible. This placed a high premium on the brightness performance of the devices. A small flight trial to assess this attribute was undertaken using a BAC1-11 twin jet aircraft used as a flying laboratory. Whilst the aircraft was flown at various flight levels, a representative device was assessed for contrast against clear sky backgrounds, bright clouds and also viewed looking close to and into the sun. This was conducted by several subjects. Measurements were taken of the background illumination using a hand held photometer. Video recordings were also taken with the camera viewing the scene through the combiner but it was realised that this was not very satisfactory as a performance measure although it provided a useful record of the trial procedures. Tests were conducted looking through the cockpit and side windows of the aircraft. The contrast when viewed through a standard sun visor was also measured. The results were encouraging, giving a good legibility against all the backgrounds. It was estimated that adequate contrast was maintained to within a few degrees of the sun.

3.2 Colour

The previously mentioned simulator trials had utilised HMDs based on 32×32 element array LED matrix as well as fixed format LED raticle displays. Both of these happened to be red and, based on the evidence accumulated during that programme, the use of red seemed to have advantages. The red colour offered good contrast against the outside world. It allowed a natural coding of the information available to the pilot, differentiating between the green of the head up display (HUD) and the red of the HMS when the sight is used within the HUD field of view. In a dynamic situation the possibility exists for the pilot to confuse movements of the HMD with control inputs or movement of a HUD symbol with head movement. Early evidence of this was seen in RAE HMD trials in the mid 1970s when on several occasions pilots attempted to control the flight path during simulated low level missions by raising their line of sight instead of applying a control input. It should be stressed that at that time display drive algorithms had not matured. However, it does illustrate the need for a display system which does not lead to misinterpretation at periods of high workload. Furthermore, it highlights the requirement for an integrated systems approach to cockpit display system design.

Based on these factors, and also to a large extent driven by the availability of components which met the other

performance requirements, notably size and brightness, it was agreed that red was a reasonable colour with which to start.

3.3 Symbology

It had been shown during the simulator trials that the amount of information available to the pilot had to be kept to a minimum consistent with allowing him to successfully prosecute the mission. The number of elements available on an LED reticle forced an economy of symbols.

The requirements of a weapon system dictate that sufficient, easy-to-interpret information must be available for the pilot to make effective use of the system. For instance, the angle at which a missile seeker is pointing relative to the aircraft is obviously limited and the pilot needs to know whether it is at the limit. Also, should the pilot look away from a target on to which the missile seeker is 'locked', it is essential that he is able to find the target again without difficulty. An obvious requirement is to provide an aiming mark.

Thus the typical symbol requirements for a simple designation system can be summarised as:-

- an aiming mark, giving the pilot an indication of where the system believes his head is pointing
- a symbol to indicate that the seeker/sensor has found a target
- a symbol to indicate that the seeker/sensor has locked onto the target
- a means of cueing the pilot to where the seeker/sensor is pointing, *ie* the target.

In addition, an indication that the head position sensing system is functioning was found to be beneficial. If the pilot's head strays outside the volume in which the HPS is effective, the drive signals cease to be effective. An indication of this is imperative. In the event of the pilot's head leaving the HPS motion box, a symbol flashed.

In directing the pilot where to look, arrow heads were illuminated to indicate the direction the pilot should turn to re-acquire the seeker/sensor line of sight. Using this method, pilots found the appropriate direction quickly and without difficulty although only eight directions could be indicated, *ie* up, down, left, right, up and right, up and left, down and right and down and left.

This format was assessed in the simulator and found to be acceptable pending flight evaluation.

3.4 Pilot's controls

The cockpit was furnished with the minimum of additional controls making use of redundant switches on the control column and specially designed coaming mounted units for the head tracker and recording systems. A simple procedure to align the head tracker was formulated, requiring the pilot to aim the HMS with the HUD weapon symbology and to push an 'Align' button. This could be achieved on the ground and in flight. Brightness control was via a knob also mounted on this unit. Front and rear cockpits were made as similar as possible.

3.5 Cockpit and aircrew equipment assembly integration

In order to design the man-mounted equipment to be compatible with the rest of his personal equipment, it was necessary for the project team to become involved in areas in which they had little or no experience.

For example, the way in which the electrical connections from the aircraft through the ejection seat to the helmet required specialist advice. After assessming the various options it was decided that, rather than modify the existing personal equipment connector (PEC), a workable solution which could be engineered without resorting to external agencies would be to design a special pull-off connector attached to the seat. Care was necessary to ensure that the connection was positive, rugged, reliable and that the design permitted the full range of seat height adjustment and cockpit movement. The connector chosen which met the requirements was a D-type which was attached to the seat via existing holes and found to be very satisfactory (see Fig 11). This connector carried all the experimental wiring to the helmet (for the Alpha-sight) or oxygen mask (for OMMS) as well as the head tracker sensor. Mic/tels connections used the standard PEC.

The routing of the wiring on the pilot was arranged with the assistance of the RAF Institute of Aviation Medicine (IAM) at Farnborough. Restrictions to the pilot's head mobility were prevented by careful design and rudimentary testing. To enable the helmet to be disconnected a special miniature man-mounted connector was fitted to the life preserver (see Fig 12). The life preservers used in the trial were modified to ensure that the man portion of the D-type connector mentioned in the previous paragraph could be pulled off at the man-seat separation phase of the ejection sequence.

3.6 Optical properties

The optical properties of the dichroic combiners used on both the OMMS and AHMS were of necessity a compromise between being sufficiently reflective at the LED wavelengths to ensure adequate image brightness, and not being so obtrusive as to provide an unacceptable distraction. The ideal solution of course is a narrow band source and an accurately matched narrow band reflector to ensure the best reflective properties, the least colouration of the scene and maximum outside world transmission. The technology which provides these ideals is holography but the technique of applying holograms to polycarbonate visors was not sufficiently developed at the time.

An essential feature of the sights was that the image had to be collimated, that is presented at near infinity. Any decollimation would cause blurring of the image when the pilot focused on a distant target or a blurred target if focused on the sight image. This, and any re-accommodation to view the HUD, are both highly undesirable.

A further critical parameter of the optical design is the exit pupil. This determines the effective porthole through which the whole sight format may be seen. Provided the pilot's pupil remains within the exit pupil there will be no vignetting of the display. The smaller this is, the more critical becomes the stability of the helmet on the pilot's head. The trade-off is that, with conventional optics, the larger the exit pupil the larger and hence heavier the optical components. Provided the AHMS is correctly fitted, there appeared little slippage of the helmet on the pilot's head, even under large and rapid movements. The design

aim for the Alpha sight was 15 mm. The OMMS presented a different set of circum-stances as the stability of the oxygen mask as an optical platform was unknown. The exit pupil for this device could not be specified as the optical design had already been determined at 15 mm.

The clearance between the nearest optical component and the pilot's eye, the eye relief, becomes a major concern in the fast jet environment where the relative movement between the head and helmet as a result of crash landing or ejection becomes extreme. The aim for the Alpha sight was 27 mm. As reported in a previous section of the report, the air blast, ejection tower and sled tests all proved that adequate clearance was maintained during the tests for the designs to be considered safe for experimental flight. The OMMS being situated not only farther from the pilot's face, was also positioned outside the visors.

4 FLIGHT TEST RESULTS

4.1 OMMS and ALPHA HMS in isolation

Before the helmet sights were used with a weapon system, both were flown in isolation using battery boxes to power the displays. These flight test sorties enabled the performance of the sights to be examined under various conditions. Of particular interest were the effects of vibration, high ambient light levels, 'g', and cockpit mobility as well as the basic concept of the pilot having a display presented wherever he looks.

The OMMS was found to behave well and the display could be seen under almost all conditions. This included some high 'g' flights in a Hawk aircraft. Visual obscuration due to the sight assembly was acceptable for test flying but a developed version would address this problem more closely. The dichroic patch on the combiner was found to require some improvement to reduce outside world colouration which was soon implemented.

The ALPHA HMS was tested under similar conditions to the OMMS but unfortunately several deficiencies became apparent almost immediately. These all involved the optical design of the display. Firstly, the dichroic patch on the visor was found to produce an unacceptable colouration of the outside world (similar to OMMS but more pronounced). Secondly, the design of the visors did not allow the clear visor to be raised independently of the dark one forcing the pilot to view the patch all the time and lastly, mechanical deficiencies in the optical design resulted in a poor display image. This highlights the potential difficulties that can occur when the visor is employed as part of the optical train.

These problems were addressed in a redesigned MK 2 AHMS which corrected the deficiencies and performed well but again, visual obscuration by the sight assembly would need to be reduced in a developed design. No difficulties were encountered with the helmet under 'g' but the lack of adjustment in the display resulted in some careful helmet fitting being required.

Both the AHMS and the OMMS gave valuable information on helmet sight performance under 'g' and vibration. Pilot acceptance of the devices was generally good although some individuals accepted the concept more readily than others. This effect sometimes made it difficult to isolate genuine problems with the helmet sights.

It was particularly interesting to note the differences between ground experiments and real conditions. In the case of 'g', minimal effects were reported unlike the difficulties observed in the centrifuge[3]. Whereas the ground experiments suggested that vibration would not be a severe problem and in flight the reverse was the case especially at low level.

Finally, the importance of robust design was emphasised during flight testing. Conducting several flights highlighted contrasting levels of care required between the OMMS and the ALPHA HMS. The latter was more prone to damage due to scratches on the visor, whereas the OMMS, although apparently more delicate, fared much better. This seemed due to more robust components and the ability to protect the optics until the pilot was ready to take off.

Thus it can be seen that this rudimentary flight testing of the devices proved invaluable.

4.2 OMMS and ALPHA coupled to a weapon system

Having tested the sights in isolation, the next step was to couple them to a weapon system so that their performance and usefulness could be more readily assessed. A particular advantage of the electromagnetic head tracker that was chosen was the small size of the sensor which had to be fitted to the sights. As indicated earlier, this sensor was positioned on the bridge of the oxygen mask for the OMMS and on the brow of the helmet for the AHMS. Care was taken to calibrate the head tracker with each device and good performance was subsequently obtained.

It was noticeable that once the helmet sights could be used as part of a designation system the deficiencies reported earlier became less important. However, this was thought to be a temporary effect until the pilots became more familiar with the concept. With the helmet sights linked to a weapon system, the symbols could be driven in response to the differing states of the system.

When used in this fashion, as part of the aircraft systems, tasks could be performed (*eg* air combat) which enabled pilots to assess the effectiveness of the helmet sights and provide a more quantitative measurement of sight performance. As before, pilots found the helmet sights effective and were able to achieve a high degree of success but the need to develop a strategy for their use and the importance of training immediately became apparent.

5 KNOWLEDGE GAINED AND LESSONS LEARNT

From the flight rest results of the OMMS and the ALPHA HMS, it can be seen that fast-jet helmet sight/displays can be manufactured and used successfully. However, to ensure that these devices can be used without undue limitations, it is crucial that every aspect is addressed carefully even with the simplest of devices. It would thus seem that taking 'large steps' in designing HMS/Ds is a very risky venture.

Human factors issues are still paramount in spite of 20 years of HMD development and study. The success of the two helmet sights described has been due to careful consideration of all the aspects involved, particularly the intended environment. Good display performance has been achieved but not at the expense of safe ejection or large weight. Additionally, both devices were designed to ensure that the pilot could capitalise on the operational enhancement of the technology without limitations to the flight envelope, mobility or other ergonomic factors.

It should be noted that technology has helped considerably in achieving these goals but that it has not been exploited unnecessarily. This has often led to problems in the past where complicated designs have been produced which are still limited in major areas (*eg* display/outside world viewability or safety).

Training with helmet displays has also been found to be important both in actual use of the device and familiarity with the overall concept. It would seem that this is as important for simple sighting displays as might be assumed for complex HMDs.

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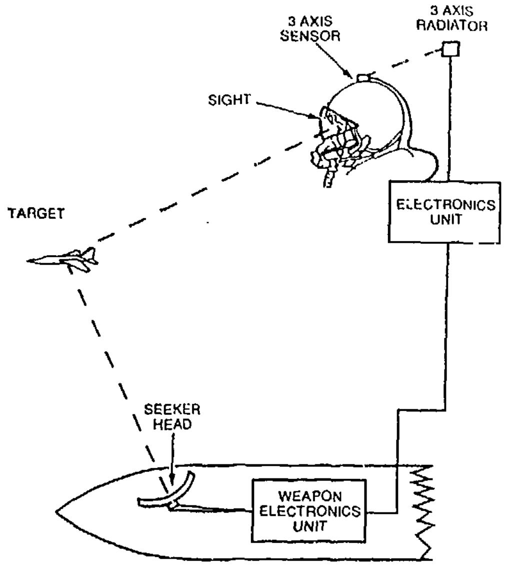

Fig 1 HMS system

Fig 2 Alpha HMS Mk II

Fig 3 Oxygen mask mounted sight

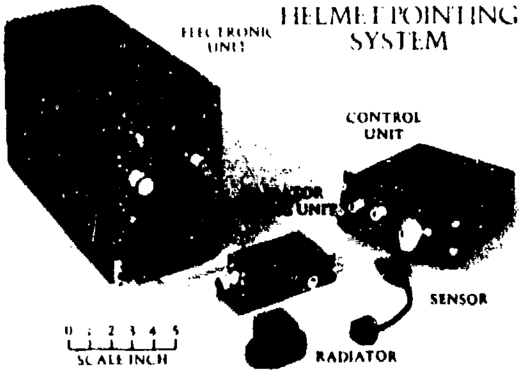

Fig 4 Head Tracker

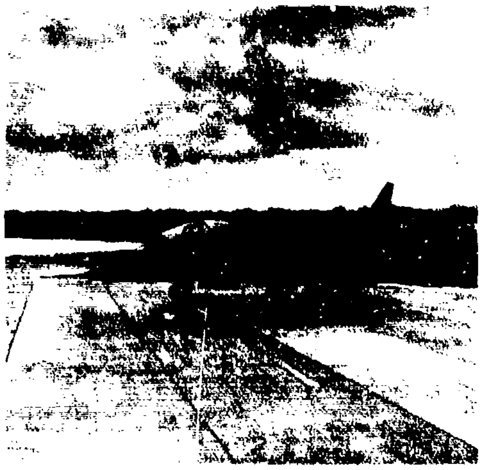

Fig 5 Jaguar trials aircraft

Fig 6 In-cockpit video picture

Fig 7 OMMS airblast test mock-up

Fig 8 Alpha HMS airblast test mock-up

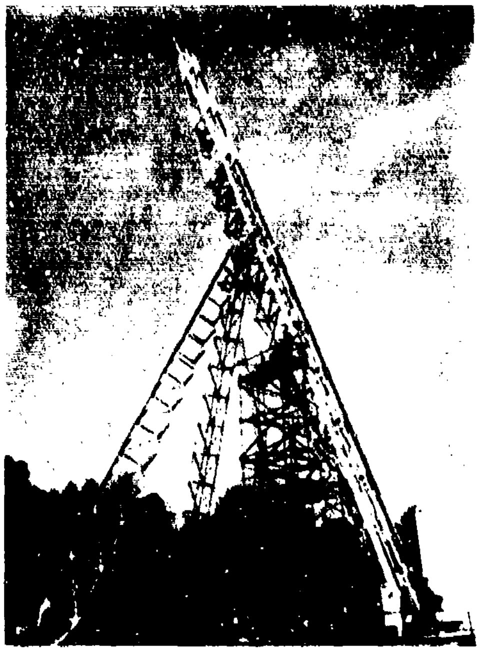

Fig 9 Ejection tower

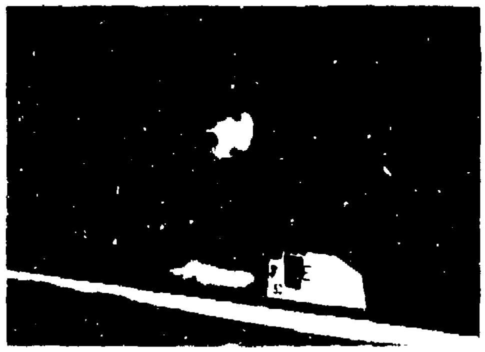

Fig 10 Rocket sled ejection test

Fig 11 Ejection seat connector

Fig 12 Life jacket cable

HELICOPTER INTEGRATED HELMET REQUIREMENTS AND TEST RESULTS

Dr. H.-D.V. Böhm and Dr. H. Schreyer

Messerschmitt-Bölkow-Blohm GmbH
Helicopter Division
Deutsche Aerospace
Post Box 80 11 40
8000 München 80, FRG

SUMMARY

A modern integrated helmet (IH) consists out of two Image Intensifier Tubes (IIT) and two Cathode Ray Tubes (CRT) with an optical system including combiners to present the images binocular. Additional symbology can be superimposed to the CRT- or IIT-image. An IH is a further development of a Helmet Mounted Display (HMD). A Helmet-Mounted-Sight (HMS) can steer a sensor platform with a thermal camera or an air-to-air missile system. The main helicopter (HC) requirements of such a system are:

- o human factors
- o optimized day, twilight and night optical modules
- o large exit pupil, good transmission of the optical path and a large adjustment range
- o fit of helmet including optimized centre of gravity(CG) and weight
- o good geometrical resolution / Modulation Transfer Function (MTF) with a large Field of View (FOV)
- o high focussing range of the IIT and a good S/N ratio below 1 mLux
- o CRT automatic brightness and contrast control
- o flight symbology presentation for one or two eyes
- o good static and dynamic HMS-accuracy with a large Head Motion Box (HMB)
- o NBC and Laser protection compatibility

MBB and the Army Corps have made in this year ground and flight trails with an Integrated Helmet and a HMS on a PAH 1 respectively a BK 117 helicopter. The paper will present IH requirements for HC application and some test results.

1. INTRODUCTION

MBB is presently under contract to the German ministry of defence to update the present **PAH 1** (anti-tank helicopter BO 105) and also to develop, in association with Aerospatiale/France, the TIGER second generation anti-tank helicopter (**PAH 2**). Both HC are expected to be capable of flying and fighting at day/night on similar missions.

The TIGER has installed in the helicopter nose a steerable platform with a 30° by 40° piloting thermal imager (**TI**). Currently the complete Pilot Visionic System (**PVS**) has two **monocular** Helmet-Mounted Sight/Displays (**HMS/D**) for the pilot and copilot cockpit. The monocular HMS/D is under contract by Sextant / VDO. The TI sensor alone can have a great disadvantage during a 24 hour mission. The absolute temperature characteristic or the emissivity of natural materials as a function of a 24 hour period will vary, ref. 1, 2, 3, 4 and 5 p. 93. A thermal zero contrast (wash out effect) during rainfall or a so called **cross-over effect** are observed especially during twilight (morning and evening). Then the foreground is not detectable against the background, so that e.g. pylons can be become very dangerous for the helicopter crew.

Therefore the combination of the two visual aids: **image intensifier tubes (IIT)** and **thermal imagers (TI)**, which are based on different physical principles, is better suited to fulfil the increased requirements of adverse weather conditions during day and night time. These two visual aids can be combined in an **Integrated Helmet (IH)** with **binocular** vision (two **CRTs** and two **IITs** on the helmet). The crew can switch between the intensifier tube image and the thermal image nearly without any delay. Additionally flight symbology can be superimposed with the images.

The available HMS-systems work on different physical principles. MBB has tested an electromagnetic AC-system in the FLAB program, ref.1 and during Gun Turret test trials. In 1990 an electromagnetic DC-system and an electro acoustic system were tested for the PAH 2 application, ref. 6.

Two suitable IHs with a HMS were tested in the MBB visionic lab. In parallel, two PAH 1 helicopters have been equipped with the Racal **RAMS** incl. GEC Avionics **KNIGHT HELM** and with an Elbit **HALO** Night Vision and Mission Management Systems. These are to be used in troop trials at Celle, FRG, to gather experience of operations with state of the art equipment before deciding on the final configuration. The first time a Night Vision System with CRTs flight symbol presentation and IITs in an **IH KNIGHT HELM** including **see-through capability** were tested on a helicopter (HC). Presently, the PAH 1 system has no TI piloting sensor. Therefore a thermal image evaluation with CRTs was not possible, but a TV image was available in the HC for IH application.

2. INTEGRATED HELMET SYSTEMS "WITH SECOND SENSOR"

2.1 Review of existing Integrated Helmets with CRTs and IITs

2.1.1 GEC Avionics KNIGHT-HELM

The basic KNIGHT HELM provides NVG operation by IITs and the CRTs generated displays of TI and symbology (FOV 35° circular). This combined IIT/CRT Helmet Display offers a high level of system flexibility and failure survival. The equipment is suited to in-service life, because all the electro-optical parts are protected by the helmet shell. New materials are being used for this helmet shell to retain strength and impact protection in a lighter weight structure. The optical modules are very compact and can be adjusted for inter pupillary distance (IPD) and can be moved slightly (up/down and fore/aft) with respect to the helmet shell. The see-through capability is mandatory. PAH 1 trail uses one day/night module but GEC has now developed a modular concept for IH. Fig. 1 shows the GEC KNIGHT HELM, ref. 7 and 8. The current status of the IH is readiness for TIGER development, if go ahead will be decided.

Fig. 1 **Integrated Helmet KNIGHT HELM** from GEC Avionics with IITs and CRTs Displays using flat eyepieces like mini-HUD prisms

2.1.2 Honeywell MONARC (Monolithic Afocal Relay Combiner)

The basic helmet has a shell which can be fitted with an individual form fit liner. With this good adaptation the helmet provides a comfortable centre of gravity. On both sides of the basic helmet are adapted the optical modules with **blocular** (only one image source but two tubes) CRT displays and **binocular** IITs (FOV 35° circular). The images of these two channels are displayed with a monolithic afocal combiner to the eyes. The see-through vision of the wearer is ensured and the field of regard is slightly obstructed. Each of the turnable combiners is part of the optical module. The optical modules can be adjusted for IPD and may be moved up and down. The MONARC was tested for several days at MBB lab and was flown for several days on PAH 1. Fig. 2 shows the Honeywell MONARC, ref. 4, 5 and 9. The current status of the IH is readiness for TIGER development, if go ahead will be decided.

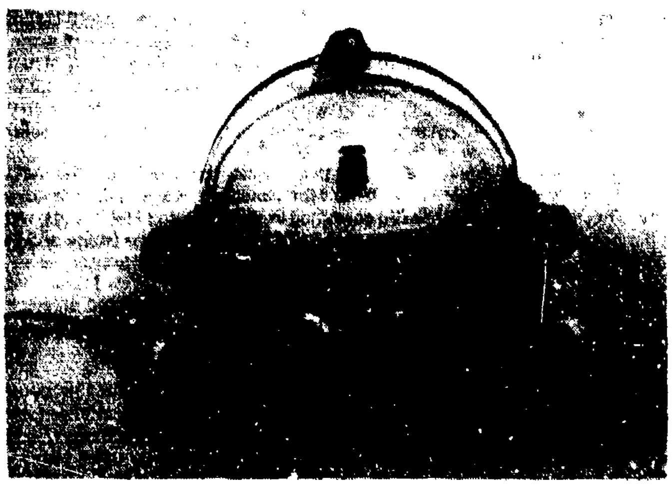

Fig. 2 Integrated Helmet MONARC from Honeywell with CRTs and IITs Displays using turnable combiners

2.1.3 Kaiser Electronics STRIKE EYE

The basic helmet has a shell which can be fitted with an individual form fit liner. On both sides of the basic helmet the optical modules with biocular (only one image source but two tubes) CRT displays (30° by 40° overlap) and binocular IITs (FOV 30° circular) are adapted in eye position. The images of these two channels are displayed with combiners from above the eyes. The see–through vision of the wearer is ensured. The combiners are retractable and adjustable, see fig. 3 and ref. 4 and 10.

Fig. 3 Integrated Helmet STRIKE EYE from Kaiser Electronics

2.1.4 Sextant/VDO Helmet Mounted Sight/Display with Light Intensifiers

The basic helmet is personalized and is generally kept by its wearer. It is a new design, using modern composite materials and optimization techniques. This was necessary to provide adequate mechanical mounting for the Day/Night Module, minimizing the helmet weight. On both sides of the basic helmet the optical modules with biocular (only one image source but two tubes) CRT displays and binocular IITs (FOV 40° circular design) are adapted in eye position. The images of these two channels are displayed with combiners from above the eyes. The see–through vision of the wearer is ensured. The combiners are retractable and adjustable. Since June 1989 a technical exchange took place between Sextant/VDO and Kaiser Electronics mainly in ergonomy field. The current status of the IH is readiness for TIGER development, if go ahead will be decided, ref. 11 and fig. 4.

Fig. 4 Integrated Helmet (proposal) from Sextant/VDO

2.2 Mission aspects and optical day / night modules

A Tactical Flight (TF) including Nap of the Earth (NOE) mission will occur approx. 25% of total flight hours and a Night Tactical Flight (NTF) approx. 15% with visual aids, that means with IIT during night or TI during day/night. An IH improves the safety analysis drastically. If a night flying system with two night sensors uses the IITs on the helmet, then the HMS, the CRTs and TI sensor platform can have a failure. The IITs have two battery packs which are independent from the HC power supply. The **reliability and flight safety** analyses including a **catastrophic fault/event** improves tremendously.

Symbology projection into one eye or two eyes for day/night application: The IH KNIGHT HELM incorporates a binocular arrangement with two **separate IITs** and separate **left and right CRT**; thus enabling full flight symbology or outside world scene via a thermal imager to be displayed in the helmet. The technique of presenting information to a pilot in this manner is complex and requires the pilot's eyes and brain to integrate the information displayed, to produce one image and not a double image.

The CRTs of KNIGHT HELM are nominally focussed to be compatible with the IITs, and the optics are designed to cope with a certain latitude in the point of focus of the pilots eyes, i.e. whether he is looking close or distant. When using TI, the IITs should be switched off, and the pilots view one image from two CRT sources. This is a usual technique. When using IITs plus flight symbology the pilot has to integrate one image from four sources; two IITs plus two CRTs. This is complicated by the **focussing** and **convergence** properties of the eye. In any case the magnification of the systems should be 1:1. Certain pilots flying the PAH 1 have had difficulties in focussing upon the flight symbology in the helmet. GEC has made investigation to confirm that the **focal plane** of the two CRTs matches that of the IITs.

Whilst two CRTs are mandatory for night flying with thermal images, two CRTs may not be necessary for night vision with flight symbology. In fact studies have shown that a pilot receiving information from CRT to one eye may not be able to distinguish which eye is receiving the information. Double images of the flight symbology or the scene appear as eye convergence is shifted to fix nearby objects while the collimated symbology is at infinity focus, by definition.

To improve the situation with PAH 1 GEC Avionics implemented a switch to allow the pilots to select manually left CRT, right CRT or both. The results were favourable; the problems associated with image separation and headaches when using flight symbology decreased and the pilots were at liberty to use two CRTs again for TI.

Auto Contrast/Brightness Sensor for CRTs: Pilots have expressed dissatisfaction that the brightness and contrast levels of the flight symbology in the **helmet–CRTs** are only manually adjustable. Under certain ambient light conditions at night, the outside light level is bright, requiring the symbol brightness in the helmet to be increased. But when the pilot then looks into foreground for example, the symbols are too bright compared with the night vision scene. To improve this situation GEC Avionics are implementing an auto–contrast control. When auto–contrast is selected, a photo detector assembly mounted on the helmet will increase or decrease the pre set contrast/brightness level dependent upon whether the pilot looks into a bright or dark area. This sensor will only affect the symbology displayed by the CRT since the IIT incorporates a separate auto brightness function.

Form Fit Liners should ensure that the helmet is **personalized** to each pilot and provide a comfortable platform for the **Integrated Helmet** with correct performance, lifetime, compliance and comfort. One of the particular problems GEC Avionics has encountered through the trials is that one helmet liner is not ideally suited to be used in two helmets of different weights, i.e. night vision only helmet and helmet with night vision and CRTs (compare chapter 2.6.). When GEC Avionics supplied the second helmet for evaluation (which contained only night vision without CRTs), there was some criticism by the pilots that the helmet **shell** was smaller and less comfortable than the first helmet supplied. In fact, the two helmets were exactly the same size despite contrary pilots comments. Indeed the second helmet was constructed with slightly more carbon fibre. This produces a much stronger shell which provides greater protection in the event of crash landing, although the shell may create the impression that it has a smaller size.

The **Centre of Gravity** (CG) of the two helmets is different. If the CG of the IH is correct, the subjective impression of the two helmets being too small may diminish. Fig. 5 shows the CG of head, helmet and NBC–mask and the different torques, which act on the head. Also the centre of head motion and the origin of force of the extensor muscle is shown. The helmet should be designed that the total torque to the head keeps nearly constant with or without helmet. This is very important specially under high g–loads. But in reality the main optic parts are located on the front side of the helmet. Therefore parts, which don't have a fixed position like e.g. batteries, should be mounted on the back of the helmet as a balancing weight. For fixed wing aircrafts a **minimum of helmet weight** is the most important point of helmet design, no additional mass, which has only a balance function, is acceptable. Otherwise the pilot gets tired and unconcentrated under the strain of a high helmet mass after a short period. For helicopter application some of the german army pilots advocate the opinion that the correct centre of gravity is the main requirement. They would accept additional mass only with balance function.

Chin Cup: Originally the KNIGHT HELM was supplied with a leather padded neck strip. The pilots expressed concern that the neck strap was uncomfortable and did not aid helmet stability. The neckstrap was exchanged for a chin strap.

During the PAH 1 flight trials it became obvious that regardless of the parameters, the **exit pupil** is perhaps the most important consideration along with **weight, field of view (FOV), resolution and brightness gain**. A large exit pupil (greater than 13 mm) provides a very user friendly system, giving great confidence and comfort by knowing that there is a large night vision window to look through. If the IH shall be moved, the pilot will not suddenly loose his vision of the outside and IIT image. A drawback of a large exit pupil is the increase of optical module weight.

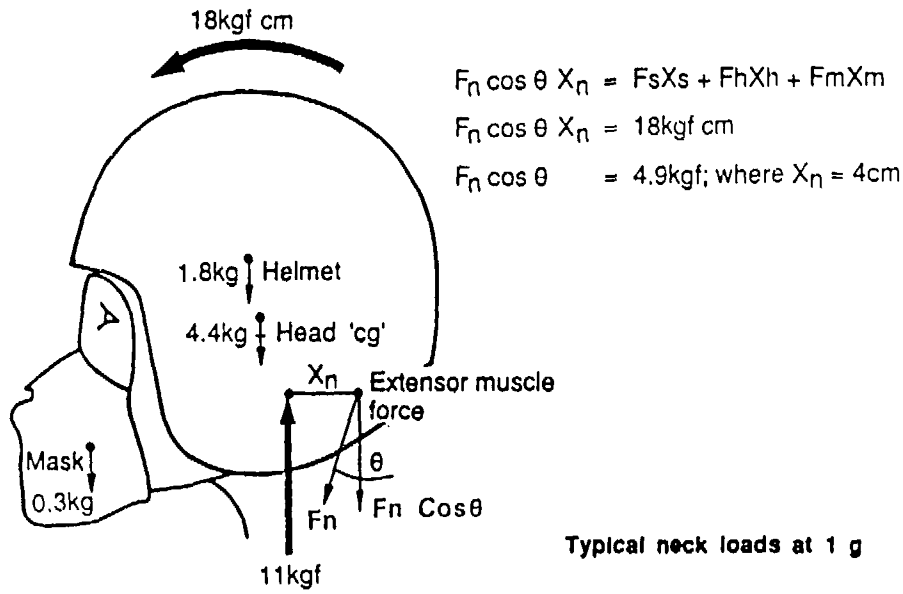

Fig. 5 Centre of gravity definition for human head. A NBC–mask is shown in this Centre of gravity diagram (ref.17).

Other important parameters of a good IH layout are:

- **adjustment comfort** for:
  - inter pupillary distance, vertical, fore/aft/tilt (eye relief)
    remark: personal adjustment on helmet;
  - divergence setting (stereo acuity), dipvergence tolerance, overlap, magnification 1:1
    remark: adjustment at supplier.
- good look around total field of regard (peripheral vision) with low obscuration of optical combiner edges, CRT– and IIT–FOV with 40° circular, magnification 1:1.
- crash protection
- Man Machine Interface (**MMI**): –wearing comfort, –usage of helmet, –cockpit workload, –Laser protection, –NBC–mask compatibility, –HID–compatibility, –cockpit illumination compatibility with IIT channel
- reliability and flight safety requirements: catastrophic fault should be zero
- speech / communication
- noise damping / active sound attenuation
- **easy modes / functions**
- fulfillment of **environment requirements** specially temperature, vibrations, EMC / NEMP
- **depth, motion** (optical flow) and **stereoscopic view perception**: biocular display gives a square root 2 advantages for two eyes in **MCT** (modulaton contrast thresholds), binocular IITs in an IH have a base line of approx. 260 mm compared to approx. 60 mm IPD in NVG, remark: problems of distance estimation arises and new training is necessary compared to NVG HC flight, magnification problems! **Ivan Sutherland** has said, ref. 4, p. 82 and ref. 13: "Although stereo presentation is important to the **three–dimensional illusion**, it is less important than the change that takes place in the image when the observer moves his head. Psychologists have long known that moving perspective images appear strikingly three–dimensional even without stereo presentation".
- **quick release connector** with high tension safety, umbilical cable
- Boresighting Reticle Unit (**BRU**) in the cockpit with easy alignment functions

2.3 Comparison of the IH–Design with a separate Day/Night or a combined Day/Night Module

2.3.1 Day Module and Night Module each separate

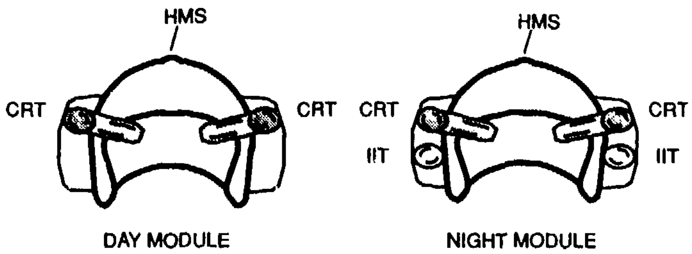

Fig. 6 Integrated Helmet with a separate day and night module

Advantages and disadvantages of a design with **separate day– and night– modules:**

advantages	– modules separate from basic helmet, each pilot has his own basic helmet (**personalized**), optical modules belong to HC – min. weight on helmet for each **day/night** mission – optimized transmission/brightness/contrast on **daytime** with 2 CRT only – optimized transmission/brightness/contrast in the **night** with 2 CRT and 2 IIT
drawbacks	– **change** of modules necessary during **twilight** – **storage** problems of modules in HC

2.3.2 One Day/Night Module

The principal design of an IH with a combined Day/Night Module is shown in Fig. 7

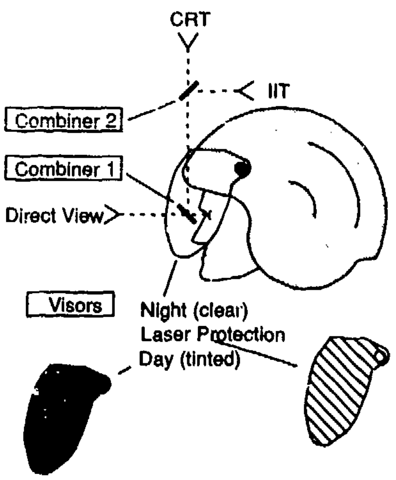

Fig. 7 Integrated Helmet with combined Day/night Module

Advantages and drawbacks of a **combined day– / night– module:**

advantages	– **no storage** problems in cockpit – mission can be flown safely **without change of modules** – minimal **parallax** between eye and night vision channel (IIT)
drawbacks	– **weight** of helmet higher than with separate modules – **transmission** levels not optimized – possibility that optical modules are fixed integrated in the helmet

⇒ Resume from GEC, ref. 5, p.92:

- It is possible to optimize a helmet display for DAY use.
- It is possible to optimize a helmet display for NIGHT use.
- But it is not possible to optimize **one helmet** display for both day and night use.

This configuration works very well in a night mission if the combiner has e.g. 70% transmission for IIT/CRT channel and a high IIT gain of approx. 5cd/sqm luminance level. However the drawback in daytime is that the combiner has an outside transmission of only 30%. This is to low for a cloudy/overcast day. To improve the day transmission for the CRT channel (brightness up to 34 000cd/sqm) an optical or mechanical switch can solve the problem, compare Fig. 8 .

Fig. 8 shows the problem area of day/night transmission splitting.

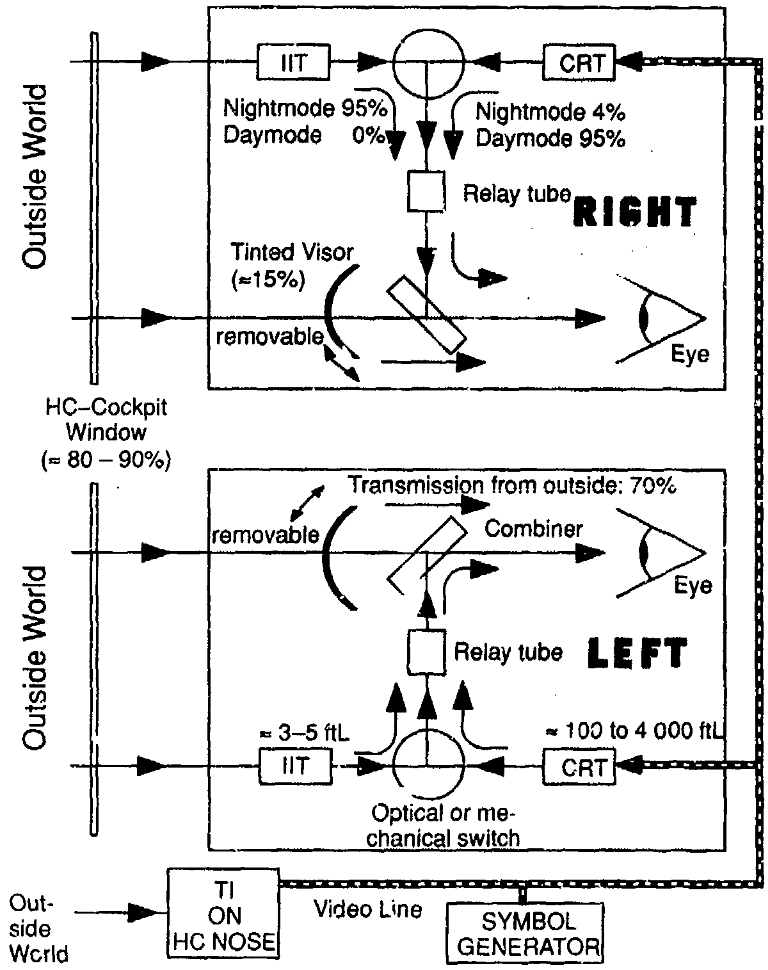

Fig. 8 Optical paths of a combined day/night module with optical or mechanical switch

2.4 Lab-Tests and HC-Trials with PAH 1 Demonstrator

The testing at the MBB laboratory was implemented for two state of the art Integrated Helmets, KNIGHT HELM and MONARC, compare fig.1 and 2. The test method for the optical IIT resolution measurement shows Fig. 9. The distance of the test target to the eye position is approx. 7m. The test pattern is a USAF 1951 target with approx. 70% contrast.

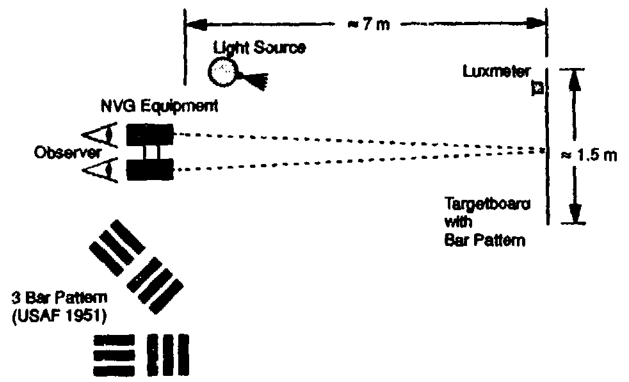

Fig. 9 Top View of the Test Set to measure the Resolution and Sensitivity of NVG's and Integrated Night Vision Helmets as a function of illumination level.

During extensive flight trials (May 90 to Jan. 91) the German Army compared the established Philips Night Vision Goggles (NVG) 3rd generation tubes with the KNIGHT HELM. In the landscape of Northern Germany, the lighting conditions under which the goggles must perform can vary over almost four decades, from 0.1 mLux to almost 500 mLux, presenting any NVG with a very severe task. The German Army is expected to fly in a particularly stringent combination of circumstances: overcast starlight, mist and precipitation at very low altitude, two or three meters above ground level between areas with obstacles. The ambient light available may be only 0.3 mLux or below. The experience shows that there is no substitute for flight trials, e.g. lab and simulator tests only, to completely understand an IH.

The Philips NVG is the benchmark of the IHs:

The Philips NVG comprises two identical straight through monoculars with fixed objective focus (approx. 10m to infinity) and adjustable eyepiece focus. The objective is a 26 mm focal length, F-No.1.2 lens with a circular field of 42° and a magnification of 1:1. The two monoculars are held together at the front on a tilting hinge for adjustment of IPD at the rear. Adjustment of IPD will vary the FOV overlap. A torch lamp is attached to the front of the binocular channels and operates by a lip switch to illuminate the cockpit, ref. 12. The resolution measurement will be shown in the next chapter 2.5.

The main results of IH including problem areas will be discussed in the next chapters.

2.5 Image Intensifier Tube - Testing

Tests were carried out at MBB on the optical performance of the IITs: Philips 3rd gen. NVG, KNIGHT HELM and MONARC. The left hand and right hand IITs were tested together with a two alternative forced choice (2AFC) method to determine resolution. Additionally the USAF 1951 test pattern was used. The objective lenses were focussed correctly with the 7m object distance. A fixed color temperature light source from an integrated sphere was available. The illumination levels were measured at the IH and in the target plane. The results are shown in fig. 10.

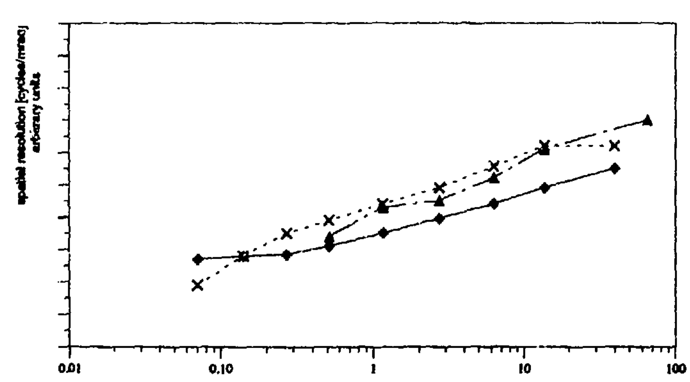

Fig. 10 Resolution tests for 3.Gen. NVG FOV 42° circ.(———), KNIGHT HELM FOV 35° circ. (–·–·–) and MONARC FOV 35° circ. (.......)

Other important parameters of a good IIT layout are:

- o good brightness at low background illumination (**LBI**) is necessary
- o Automatic Gain Control (**AGC**) lies between 1500 and 2900 at 10^{-2} cd/sqm
- o **daylight filters** (neutral filters) for training purpose are desirable with attenuation of 10^{-7} and 10^{-9}
- o 645 nm **cut off filters** with antifluorescent coating were used
- o **image quality**: snow/scintillations (S/N) and homogeneity over combiner must be good
- o **tube life time**, (InSb sealing!), temperature range with full performance between –12° C and 42° C

2.6 CRT–Testing

A 1" tube has a 25mm diameter faceplate with a screen diameter of 19mm. The spot (pixel) size is approx. 18µm at 200ftL or 25µm at 500ftL for P43 Phosphore (gaussian profile). If one considers a future requirement for a high luminance (approx. 10 000ftL) allowing daylight raster viewability then this will require at the present time a further sacrifice in resolution with a low drive value of 24µm and a high drive value of 32µm.

Other parameters of a CRT are:

- o **high brightness** necessary for day flight with symbology, same brightness of the two images
- o 10 grey levels with relative good brightness and contrast
- o **high resolution** image, approx. 18µm spot size or approx. 40 Lp/mm with good quality/homogeneity/ min.distortion, same for both CRTs
- o high brightness (approx. 4 000 ftL) with poor resolution and reduced grey levels.
- o **no vignetting** of image edges, low distorsion
- o ghost image (double image) should be zero; coating problems at IIT/CRT–beamsplitter (reflections)
- o fast Stroke (cursive) symbols written in Raster flyback / Raster display of sensor video possibility
- o **head roll compensation** necessary
- o optimized overlap, divergence and dipvergence of the two channels
- o raster scan generator shows 0.8 cycle/mrad for KNIGHT HELM and MONARC
- o circular test pattern shows low distortion,
- o electronic distortion compensation necessary
- o **high voltage isolation**

2.7 Nose or Helmet Solution for a Second Night Vision Sensor

2.7.1 General remarks to IIT–CCD sensors for use as Nose Solution

The IIT image is converted with a CCD (Charged Coupled Device) to video standard and displayed with a CRT to the eye. The alignment of IIT and TI channel is much easier.. Electronic image processing for image fusion can be used as growth potential.

A strong drawback is the dependence of power for both channels. If HC power fails no redundancy will exist. The flight safety/reliability decreases with this arrangement.

2.7.2 Second Sensor Installation Comparison between HC Nose Solution and Helmet Solution

There are two possibilities to install the IIT sensor:

- o nose solution with IIT–CCD and TI sensors, fig.11 .
- o helmet solution with IIT sensors on helmet, TI sensor on HC nose, fig. 12.

The TI/IIT–CCD sensors are located in the HC nose below the pilots design eye point steered by HMS. This can produce problems of parallax, wrong depth perception and apparent motion. However if the IIT channels are helmet mounted, there exist problems with switching of two different visual reference points.

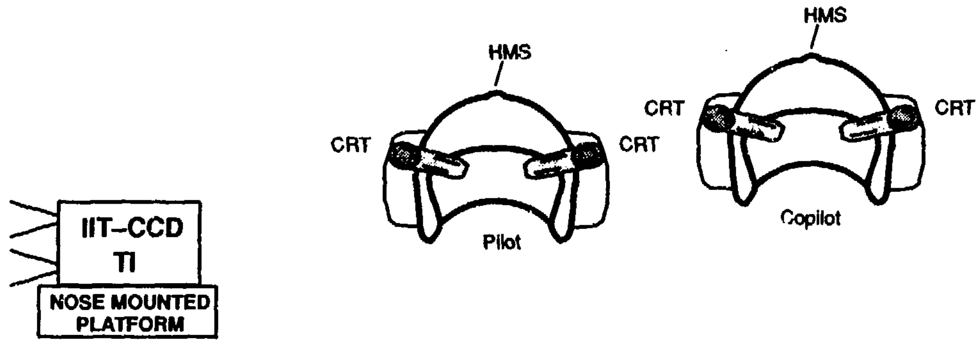

Fig. 11 **Nose solution** with IIT–CCD and IH has only 2 CRTs.

Aspects of the Nose Solution:

operational advantages	– free of parallax between sensors on platform, but not between sensor and eye (with direct view) – video signal of IIT–CCD and TI available, image processing (sensor fusion) is possible – sensors optimized for day–, twilight– and night – conditions without changing of any optical modules – lower weight on helmet
operational disadvantages	– platform slaving error in relation to the head Line of Sight (LOS) – additional equipment has to be mounted on an existing platform – less redundancy than the case with IIT only, degraded flight safety
economic and program aspects	– higher costs compared to helmet solution if an existing system shall be retrofitted

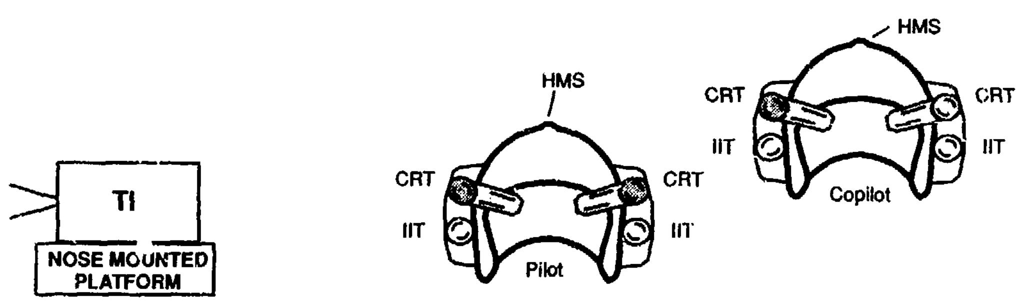

Fig. 12 **Helmet Solution** with 2 CRT and 2 IIT sensors.

Aspects of the Helmet Solution:

operational advantages	– natural use of the visual aids – no slaving error – no parallax between eye and IIT – installation easier – high redundancy – high reliability – high flight security – easy hardware update – less aircraft weight
operational disadvantages	– 2 optical modules necessary (for day and night) – parallax between TI and IIT – additional weight on helmet – image processing not possible – greater helmet complexity
economic and program aspects	– lower costs compared to nose if a retrofit of an existing system should be realized – possible solution for different types of helicopters

3. HELMET MOUNTED SIGHT SYSTEMS

3.1 Principles Of HMS – Systems

The purpose of the HMS is to steer either a platform with optical sensors, a landing light platform or a weapon platform in accordance with the head motion of e.g. a helicopter crew. Fig. 13 shows the silhouettes from TIGER–HC from the side. The measured values of the head motion angles must be of high accuracy and to be available with a minimum of time delay.

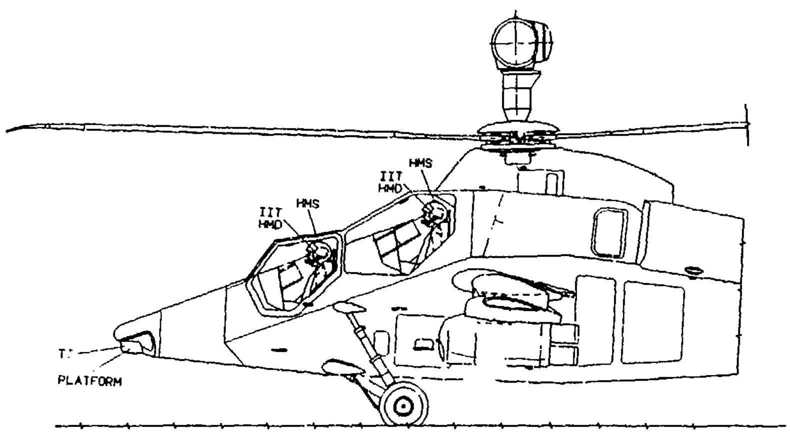

Fig. 13 PAH 2 with steerable platform and HMS–system

The helmet mounted sight systems can be realized using different physical principles. In the following the important HMSs of today are described with their main characteristics:

AC–Electromagnetic Systems (e.g. Polhemus, Ferranti, Sextant)

- based on alternating electromagnetic waves
- transmitter (3 orthogonal coils) mounted in HC–cockpit
- receiver (3 orthogonal coils) mounted on the helmet
- calculating head direction inside the Head Motion Box (**HMB**) according the induced voltages
- disturbances whilst changing metal surrounding
- cockpit mapping necessary

DC–Electromagnetic Systems (e.g. GEC Avionics)

- based on quasi–constant electromagnetic field
- transmitter (3 orthogonal coils) mounted in HC–cockpit
- receiver (3 orthogonal coils) mounted on the helmet
- receiver is working like a magnetometer
- DC–systems are less sensitive to metals as AC–systems

Electro Acoustic Systems (e.g. TST)

- based on ultrasonic waves
- transmitter (e.g. 6 pieces) mounted on the helmet
- receiver (e.g. 6 pieces) mounted in HC–cockpit
- head direction is calculated according the propagation time of ultrasonic waves
- pulse code modulation prevents disturbances from any ultrasonic noise
- disturbances due to rapid changes of dispersion medium air are possible, the influence of normal cockpit airflow is compensated

Pattern Recognition systems (e.g. ELOP)

- receiver is a CCD camera mounted in the HC–cockpit
- transmitter is a geometric pattern which is painted on the helmet or a pattern of LEDs which is mounted on the helmet
- head direction is calculated with the aid of image processing of the video image of the pattern on the helmet
- disturbances whilst sensor saturation due to direct sun light illumination
- problems in detecting the geometric pattern during night

Electro Optical Systems (e.g. Honeywell, IHADSS)

- transmitters are special units, mounted in the HC–cockpit, emitting pulsed IR–radiation
- receivers are two IR–detector sets mounted on each side of the helmet
- problems may occur if direct sunlight disturbs the detectors

3.2 Test Procedures

3.2.1 Error Definition

An important point for understanding and comparison of tracker errors is an exact definition of the errors.

In Fig. 14 we have plotted the error definition. The diagram shows the statistics of measurements of a common value. Plotted on the y–axis is the occurrence of the feed back value of the measurements. There is a distribution of the values around a maximum of occurrence.

The maximum error is calculated by the difference between command value and feed back value plus the reproducibility of the feed back value. This maximum error has two different error types: the **systematic error** and the **statistic error**.

Systematic error:

The deviation between **command value** and measured **feed back** value depends on the command value. It can not be given as a general function, because the dependence is specific to the HMS–alignment. This is a systematic error. If the measurement system is well known and has a good reproducibility this error could be corrected. In case of a HMS–system this will be done by cockpit–mapping and after full system development the systematic error should be nearly zero.

Statistic error:

The most important error value is the reproducibility (σ). This value determines the minimal approachable system accuracy. The tolerance values can be defined in σ – or standard deviation (SD) values. Chapter 3.3.2 describes also the circular error probability (CEP) for σ_x (AZ) and σ_y (EL).

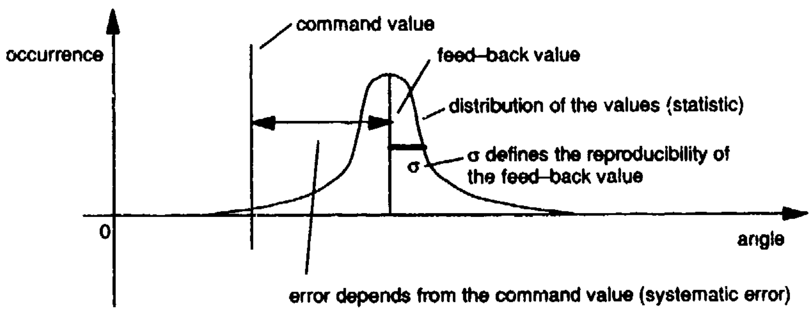

Fig. 14 Error Definition

3.2.2 Test Equipment

In fig. 15 the principle setup of the MBB accuracy test rig is shown. The basis of the rig are two metal plates. Three mounting screws allow a vertical adjustment and a tilting of the plates together. On the upper plate the stepper motor for the azimuth movement is fixed. The whole helmet fixture is mounted on this motor. Additionally an angular steel support is fixed to mount a second stepper motor with vertical axis. This motor is connected with a mechanical linkage which allows the movement of the helmet in elevation.

One requirement to the test rig is the use of non–metallic materials above the stepper motors to be able to test HMS–systems on electromagnetic basis. Metallic influences of the test rig itself cannot be accepted during testing.

The movement of the helmet in azimuth and elevation is **fully automated and computer controlled**. The command values can be given from a PC. A **special software** converts the angle values to motor steps and controls movement, velocity and acceleration of the motors. The maximal resolution of the stepper motors is 0.01° at a maximal velocity of 100°/s. The helmet movement in roll can be done manually in steps of 15°.

The **maximal angle range** of the helmet movement is limited by the mechanics of the test rig to:

- azimuth +/–180°
- elevation +25°, –30°
- roll +/– 45°.

The **accuracy** of the MBB testrig has been tested and has the values of:

- 0.01° in azimuth and
- 0.05° in elevation.

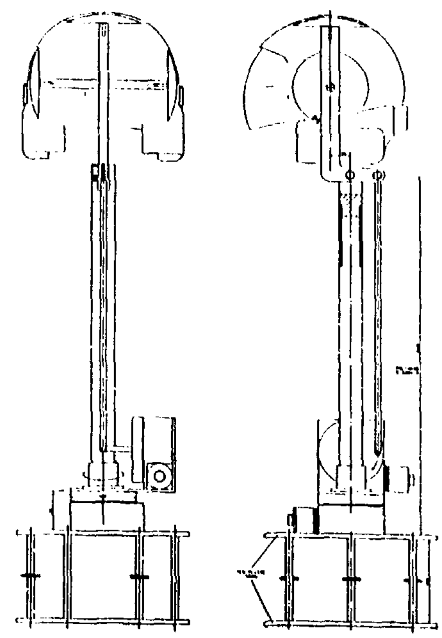

Fig. 15 MBB Test Rig for Helmet Mounted Tracker Evaluation

Installation of the test rig in the helicopter (Fig.16):

- A wooden table which can be adjusted vertically is mounted over the pilot's seat.
- The helmet including the transmitter respectively receiver is mounted to the test rig.
- The test rig is fixed with screws on the wooden table. The test rig may be adjusted in height as well as in tilt to the helicopter frame.

Fig. 16 Test Rig with Helmet and HMS in a BK 117 helicopter (TST – electro acoustic system)

3.2.3 Test Program

We have divided the test program into two parts, **static measurements** and **dynamic measurements**.

3.2.3.1 Static Measurements

The HMB is defined as the movement area of the pilots head. Inside this HMB the specified accuracy of the HMS–system has to be verified. The dimensions of the HMB vary from helicopter to helicopter, for an example Fig. 17 shows a HMB of 400mm x 400mm x 200mm with selected measurement points.

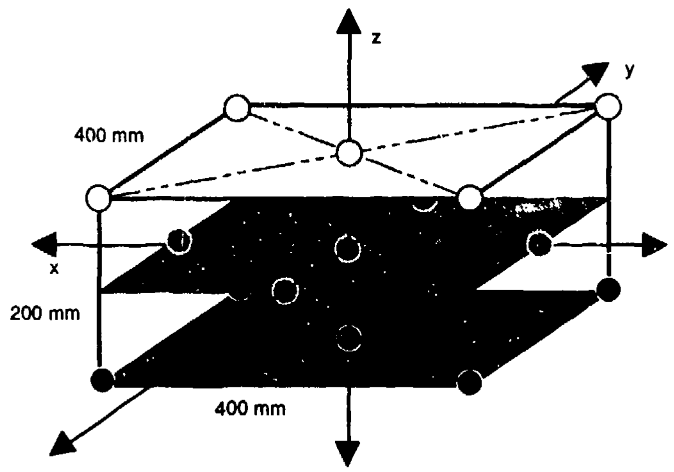

Fig. 17 Testing Positions inside the Head Motion Box

In the static part we have measured the accuracy of the HMS–system in the centre of the HMB with an enhanced set of angles:

elevation angles of 0°, +20°, –20° in combination with the azimuth angles:
0°, +/–5°, +/–10°, +/–15°, +/–20°, +/–25°, +/–30°, +/–45°, +/–60°, +/–75°, +/–90°,
and roll angle 0°

and the elevation angles of +10°, –10° in combination with the azimuth angles:
0°, +/–15°, +/–30°, +/–45°, +/–60°, +/–90°

Test procedure in the centre of HMB:

- Boresighting of the HMS–system.
- For one fixed elevation angle the complete set of azimuth angles will be commanded step by step and for each point the HMS angle measurement values for azimuth, elevation and roll will be noted.
- This set of azimuth angles with the fixed elevation value will be measured for several (e.g. 10) times. Out of these values we calculate the maximum of the absolute error and the reproducibility (standard deviation).
- The above mentioned measurement has been repeated with all elevation angles.

Measurements of different roll angles are carried out in steps of 15° with azimuth = elevation = 0°.

In the all other points of the HMB (compare Fig. 17) a reduced set of measurement was carried out with elevation angles of 0°, +/– 20° in combination with azimuth angles : 0°, +/– 15°, +/–30°, +/– 60°, +/– 90°.

3.2.3.2 Dynamic Measurements

Dynamic measurements are necessary to ensure that the delay between head movement and the electrical output is in an acceptable frame. Long delays decrease the flight safety if e.g. a steerable FLIR is used for piloting.

For verifying the delay the test rig including the helmet carries out periodic movements in azimuth. For this movement the stepper motors of the test rig may realize a maximum velocity of 100° per second. In the computer protocol the output values can be compared with the stimuli and may be checked for achievement of the maximum values and the maximum velocity at the zero point.

3.3 Test Evaluation of an Electro Acoustic HMS–System from TST (Telefunken System Technik)

3.3.1 Static measurements

Calculation of mean values, standard deviation (n–1) and the absolute errors (command– minus feed–back values) according to the above mentioned test plan. As result we get the absolute errors as well as the reproducibility of azimuth (fig. 18), elevation and roll.

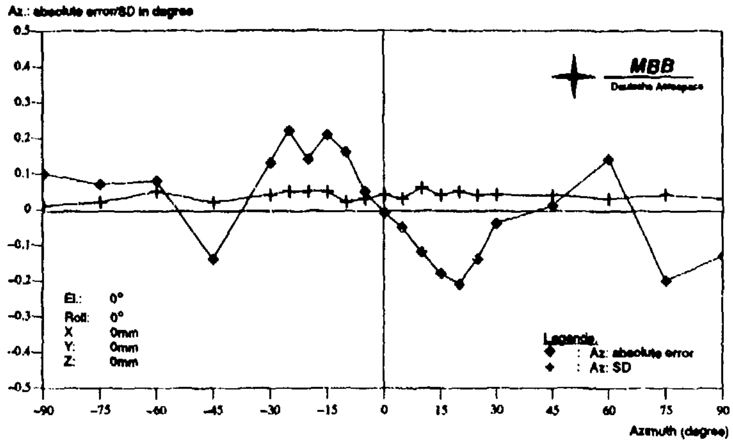

Fig. 18 Absolute error of azimuth and standard deviation as a function of the azimuth angle (electro–acoustic system).

The result of a complete measurement are about **100 of these diagrams**. For an overview of the accuracy a data reduction has to be implemented!

3.3.2 Data Reduction

Calculations of the mean value of the absolute errors and the mean value of the SD for **all angles** (separately done for azimuth, elevation and roll), which were measured during one scan of azimuth with constant elevation angle are shown in fig. 19. The maximum and the minimum values are also mentioned to see the bandwidth of the error. Additionally the circular error probability (99.9% probability) $CEP_{0.999}$ is calculated. The approximation formula for $CEP_{0.999}$ is (ref. 15.)

$$CEP_{0.999} = \sigma_y(3.408 - 0.643\rho + 0.923\sigma^2)$$

with $\rho = \sigma_x/\sigma_y$ and $\sigma_y > \sigma_x$.

This procedure is done for each measurement point.

MBB Deutsche Aerospace		AZIMUTH (°)			ELEVATION (°)			CEP 99.9% (°)		
El. angle		min.	mean	max.	min.	mean	max.	min.	mean	max.
0°	abs. error	0.01	0.12	0.22	0.02	0.25	0.86			
	SD	0.01	0.04	0.06	0.01	0.03	0.05	0.037	0.14	0.22
+10°	abs. error	0.09	0.24	0.50	0.04	0.36	1.08			
	SD	0.01	0.03	0.05	0.01	0.02	0.03	0.037	0.10	0.17
–10°	abs. error	0.01	0.29	0.54	0.01	0.35	0.72			
	SD	0.01	0.03	0.04	0.02	0.02	0.05	0.058	0.10	0.17
+20°	abs. error	0.01	0.58	1.26	0.00	0.33	1.16			
	SD	0.01	0.04	0.07	0.02	0.03	0.06	0.066	0.14	0.25
–20°	abs. error	0.01	0.45	0.70	0.00	0.37	0.77			
	SD	0.02	0.04	0.06	0.01	0.03	0.07	0.066	0.14	0.25

Fig. 19 **Mean value of the absolute errors and the mean value of the standard deviations for all azimuth and elevation angle values, which were measured during one scan of azimuth with constant elevation angle (electro acoustic system). The 99.9% circular probability is calculated in the third column.**

Fig. 20 shows the azimuth and elevation SD mean values over all measured azimuth angles (with constant elevation angle) and the $CEP_{0.999}$ as a function of the elevation angle for one point inside the HMB.

Fig. 21 shows azimuth, elevation and roll mean values of the absolute error and the SD (calculated like the values in fig. 19 for the elevation angle 0°) for different points inside the HMB. Fig. 22 is a diagram in which the mean values of the absolute errors in azimuth, elevation and roll are plotted as a function of one dimension of the HMB.

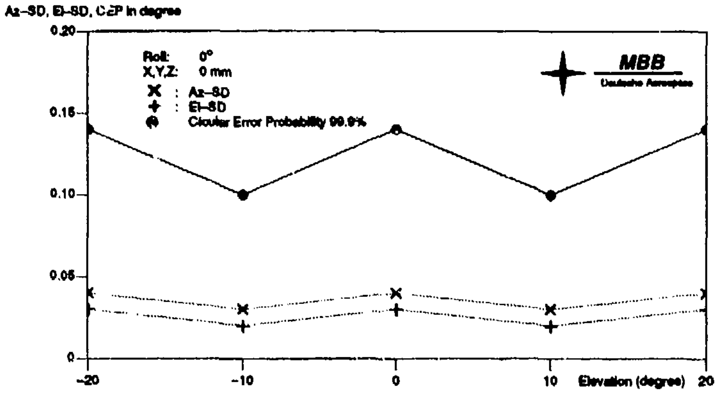

Fig. 20 Azimuth and elevation mean values of the standard deviations over all measured azimuth angles (with constant elevation angle) and the 99.9% circular probability as a function of the elevation angle for one point inside the HMB (electro acoustic system).

		HMB – Position		
		X= –100 / Y,Z = 0	X, Y, Z = 0	X = +100 / Y, Z = 0
Mean value of absolute error	Az. El. Ro.	0.15° 0.34° 0.29°	0.12° 0.25° 0.27°	0.09° 0.33° 0.42°
Mean value of SD	Az. El. Ro.	0.02° 0.02° 0.02°	0.04° 0.03° 0.03°	0.02° 0.02° 0.02°

Fig. 21 Mean values of absolute errors and general SD for azimuth, elevation and roll for different HMB – Positions.

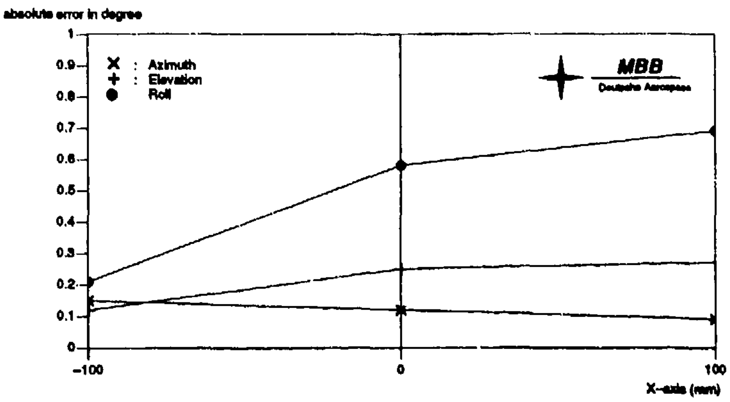

Fig. 22 Mean values of absolute errors for azimuth, elevation and roll as a function of one dimension of the HMB (electro acoustic system).

3.3.3 Dynamic Measurements

For the dynamic measurements we have connected the HMS measurement values of the azimuth angle to an x–t recorder, while the helmet on the testrig carries out periodic movements. In fig. 23 achievement of maximal angles can be checked. Additional the HMS output for the maximal velocity of the movement (calculated according the slope of the curve) can be compared with the commanded motor velocity.

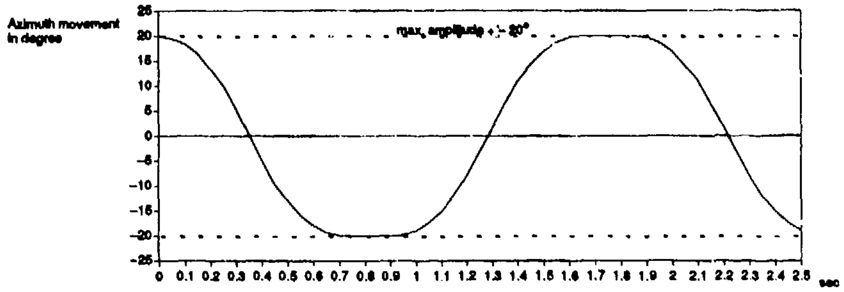

Fig. 23 Time Plot of the dynamic measurements (electro acoustic system), max. test rig velocity is 100°/s.

3.3.4 Additional Measurements

The following additional measurements have been included in our measurements:

- o controlling the longtime stability of the electronics (2h)
- o qualitative disturbance measurements, especially for the tested HMS, e.g.:
  - AC–,DC–systems: additional metal parts between transmitter and receiver
  - DC–systems: influence of the magnetic earthfield
  - Electro Acoustic systems: switching on the helicopter ventilation, thermal changes in the cockpit, as e.g. direct sunlight
  - Optical systems: sensor saturation due to e.g. direct sun illumination
- o influence of running engines and rotors:
  - electric disturbances
  - acoustic disturbances
  - helicopter vibrations

4. CONCLUSION

The helicopter flight trials and laboratory tests are carried out to gather experience of operation with state of the art IH equipment before deciding on the final configuration. The extensive trials showed that there is no substitute for flight trials, e.g. laboratory and simulator tests only, to completely understand an IH for day and night flight capability. The difficult human engineering aspects have to be evaluated with functional IH models to find the necessary improvements.

The work of this paper is partly a result from a HMS measurement campaign on BK 117, visionic lab tests and troop flight trials with PAH 1. These programmes were launched by "Bundesamt für Wehrtechnik und Beschaffung" (BWB) and "Bundes Ministerium für Verteidigung" (BMVg, German Ministry of Defence)

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AN EVALUATION OF THE PROTECTIVE INTEGRATED HOOD MASK FOR ANVIS NIGHT VISION GOGGLE COMPATIBILITY

Mary M. Donohue-Perry

Armstrong Aerospace Medical Research Laboratory
Human Engineering Division, Crew Systems Effectiveness Branch
Wright-Patterson Air Force Base OH 45433-6573, USA

Joseph T. Riegler
Logicon Technical Services, Inc.
P.O. Box 317258
Dayton OH 45431-7258

SUMMARY

An evaluation was conducted to determine potential compatibility problems found while using the Protective Integrated Hood Mask (PIHM) with the Aviator's Night Vision Imaging System (ANVIS). The evaluation consisted of field tests performed at Pope AFB using qualified C-130E crewmembers, and laboratory tests conducted at Wright-Patterson AFB. Examinations of horizontal and vertical intensified fields of view, cockpit lighting compatibility, and a subjective evaluation of fit were conducted at Pope AFB. Visual acuity through ANVIS/PIHM, and distortion and transmissivity of the PIHM visor were determined at WPAFB. Acuity through ANVIS with and without PIHM was assessed under quarter moon and starlight illuminations. Acuity was tested using 20% and 90% contrast Landolt C targets depicted in one of four orientations. Overall conclusions were that potential compatibility problems of ANVIS and PIHM integration can be reduced or eliminated with proper fit and adjustment of the ANVIS/PIHM.

INTRODUCTION

The Aircrew Eye Respiratory Protection System (AERPS) is designed to protect USAF aircrew members in a potential or known chemical environment without imposing physiological burdens or degrading mission capability. The Protective Integrated Hood Mask (PIHM) is the candidate subsystem of AERPS for use by aircrew members of tanker, transport, and bomber aircraft. As shown in Figure 1, the PIHM is designed to be worn under a standard HGU-55/P flight helmet.

Figure 1. Field test subject wearing PIHM/ANVIS combination.

Prior to C-130E flight testing, the Life Support SPO (HSD/YAG) requested AAMRL/HEF to evaluate potential compatibility constraints that may result from wearing the Aviator's Night Vision Imaging System (ANVIS) with the PIHM. The method used to integrate PIHM with ANVIS consists of a special helmet mounted bracket that allows ANVIS to be positioned just in front of the PIHM visor. Integration of PIHM with ANVIS results in the PIHM visor being located between the user's eye and the ANVIS objective lens, and could result in limitations in aircrew visual capabilities during NVG missions.

AAMRL/HEF conducted laboratory and field studies at Wright-Patterson AFB, Ohio (WPAFB), and Pope AFB, North Carolina, respectively. The field study used qualified C-130E pilots to evaluate the following parameters: PIHM/ANVIS intensified field of view, cockpit lighting compatibility, and photographic and subjective evaluations of

system fit. Visual acuity, distortion, and transmissivity were evaluated at WPAFB. Results from both studies are presented in this paper along with conclusions and recommendations for the PIHM/ANVIS integrated system.

METHODS

Subjects

Subjects for the field evaluation were five rated male C-130E crewmembers (two pilots and three navigators) who had a minimum 100 flight hours with NVGs. The participants for the lab evaluation were fourteen subjects who ranged in age from 21-45 years and had 20/20 or corrected Snellen acuity. All subjects received assistance in proper PIHM and helmet fit by a life support specialist.

Apparatus

The field evaluation was conducted in a darkened hangar at Pope AFB after dusk. Natural lighting conditions approximated quarter moon illumination. Intensified field of view measurements were obtained for each subject using a 5 foot square visual field. A light emitting diode (LED), positioned in the center of the field, was used as a fixation point. A second LED, which moved along a vertical and horizontal scale, was used to measure the vertical and horizontal intensified fields of view. The cockpit lighting interference evaluation was performed in the crewstation of a C-130E aircraft. A pair of Mil-specification ANVIS third-generation night vision goggles (NVGs) were mounted with velcro strips to an HGU-55/P with a mounting bracket developed by the Special Mission Operational Test and Evaluation Center (SMOTEC), located at Pope AFB.

The evaluation at WPAFB was performed in the AAMRL Night Vision Operations (NVO) laboratory. Visual acuity was measured with Landolt Cs having modulation contrasts of 90% and 20% mounted on a white foam core background. Each acuity chart consisted of three to five Landolt Cs of the same contrast in one of four orientations: up, down, right, or left. A moonlight simulator developed at AAMRL set to approximate quarter moon (.00294 ft-L) and starlight (.000319 ft-L) illumination levels was used to provide calibrated illumination on the surface of the chart. Landolt C sizes (in Snellen notation) ranged from 20/32 to 20/71 for quarter moon illumination, and from 20/80 to 20/300 for starlight illumination. The same mounting bracket used for the field evaluation was also used in the laboratory to mount the ANVIS to the HGU-55/P helmet.

PROCEDURE

Field of View

Horizontal and vertical intensified fields of view were measured for each subject first with the HGU-55/P helmet and ANVIS (baseline); and then with the PIHM/ANVIS combination. The field of view (FOV) measurement procedure was identical for both baseline and the PIHM/ANVIS combination. Optimum baseline FOV was obtained by having the subject adjust ANVIS until a 40° FOV was obtained. The procedure for measuring the FOV was as follows. The subject was positioned in a chin rest located so that the ANVIS objective lenses were 6 feet from the LED fixation point. After initial ANVIS adjustment, the subject was instructed to close one eye and fixate on the center LED. The experimenter then moved a second LED inward along a vertical or horizontal scale beginning at a 22° FOV. The subject indicated when the LED was just visible at the edge of the intensified field. This procedure was repeated twice for each eye in both the vertical and horizontal dimensions. The average of the two left and right side measurements was added together to obtain the total FOV for each eye.

Cockpit Lighting Interference

Cockpit lighting interference was evaluated for two different viewing modes: 1) viewing through the PIHM/ANVIS and 2) viewing through the PIHM visor but underneath ANVIS. Subjects performed the cockpit lighting evaluation seated at the pilot's station of a C-130E cockpit. The subject was asked to set the cockpit lighting at a comfortable ANVIS mission level. He then viewed an acuity chart positioned at eye level 20 feet from the windscreen and indicated any reflections that were present. The sources causing the reflections were documented. Subjects then viewed the crewstation through the PIHM, but underneath ANVIS, and noted any reflections. If no interferences were noted, the test was terminated.

Fit

Front and side view photographs were taken of each subject wearing the ANVIS both with and without PIHM. The photographs were used to document any specific fit problems with PIHM/ANVIS. A questionnaire was also administered to the subject which addressed PIHM/ANVIS fit and visibility.

Visual Acuity

Visual acuity measurements were obtained for six of the laboratory subjects while wearing the ANVIS alone (baseline) followed by measurements with the PIHM/ANVIS. Measurements were made for 20% and 90% contrast Landolt Cs at both quarter moon and starlight illumination levels. Most of the measurements were completed with the ANVIS objective lens located at a distance of 30 feet from the acuity chart. The ANVIS

objective lens was required to be placed at a distance of 12 feet from the acuity chart for the low contrast letters when they were viewed under starlight luminance levels. The subject's task was to read from left to right the orientation of the Landolt Cs. Each subject viewed 23 charts of different letter sizes for both the baseline and PIHM/ANVIS conditions. Acuity chart presentation order was randomized for each condition. Visual acuity was the letter size at which at least 75% correct orientation responses were made.

Distortion

The angular deviation of three PIHM visors was measured using a UDT light source and a two-dimensional array. For each eye position, measurements were recorded from -15° to +15° in 5° increments for both azimuth and elevation. The data from the two eye positions were compared to obtain vertical and horizontal differences in angular deviation between the two eyes. Distortion was further assessed by taking photographs through each visor of a large grid board positioned ten feet in front of the camera. These photographs were visually examined for distortion.

Transmissivity

The spectral transmission of three PIHM visors was measured for wavelengths of 380-760 nm using a Photo Research 1980B spectral scanning radiometer. The photopic transmissivities of several objects (both natural and man-made) that would be found external to the crewstation were calculated. The results of these calculations were compared to a standard Air Force clear visor (which is a neutral material) to determine if visibility through the PIHM visor was significantly different.

RESULTS

Field of View

Horizontal and vertical intensified fields of view were measured for PIHM/ANVIS monocular and binocular viewing. Mean and standard deviations for these measurements are presented in Table 1.

Table 1. Mean and standard deviation for horizontal and vertical intensified fields of view for monocular and binocular viewing measured at AAMRL (in degrees of visual angle).

	HORIZONTAL			VERTICAL		
	MONOC. RT.	MONOC. Lt.	BINOC.	MONOC. Rt.	MONOC. Lt.	BINOC.
MEAN	36 °	36 °	38 °	37 °	36°	37 °
STD	2	3	2	3	2	2

The addition of the PIHM resulted in a 10% horizontal FOV loss for each individual eye (compared to the ANVIS baseline 40 degree FOV), and a 5% loss for the binocular view. Changes in vertical FOV from a 40 degree baseline level ranged from 7% to 10%. These FOV reductions should not present any significant problems. Field of view data collected at Pope AFB with C-130E crewmembers wearing PIHM/ANVIS resulted in average horizontal and vertical fields of view of 36.2 degrees and 36.0 degrees, respectively, which is comparable to the laboratory data.

Cockpit Lighting Interference

There were no cockpit lighting interference problems reported when viewing through the PIHM/ANVIS or through the PIHM under the ANVIS. One subject found lighting interference upon entering the crewstation when the lights were at a high setting, but these reflections were eliminated when set to normal night mission levels.

Fit

The photographs taken of each C-130E crewmember while wearing the ANVIS both with and without the PIHM showed that the ANVIS oculars were in proper alignment for all of the subjects. No problems were found with the mounting bracket while wearing the PIHM. To ensure optimal field of view, the oculars were positioned as close to the visor as possible (approximately 10-20 mm), but they did not come in contact with the visor. The questionnaire results showed that two subjects reported better visibility through the PIHM/ANVIS because the "graininess in the NVGs was less." The remaining three subjects reported that their visibility was the same for each viewing mode. Two subjects reported restricted side-to-side head mobility while wearing the system. All subjects reported the intensified FOV with PIHM/ANVIS appeared to be unchanged from viewing with ANVIS without the PIHM.

Visual Acuity

The mean visual acuity measured at the quarter moon and starlight illumination levels for the 20% and 90% contrast Landolt Cs for ANVIS and PIHM/ANVIS viewing is displayed in Table 2.

Table 2. Mean Snellen visual acuity for ANVIS and PIHM/ANVIS viewing under quarter moon and starlight illumination for 20% and 90% contrast Landolt Cs.

	QUARTER MOON		STARLIGHT	
CONTRAST	20%	90%	20%	90%
ANVIS	20/50	20/38	20/229	20/96
PIHM/ANVIS	20/53	20/40	20/229	20/94

There were only slight differences in visual acuity between baseline ANVIS and PIHM/ANVIS viewing. These differences were not statistically significant ($p > .05$) for either illumination level.

Distortion

Differences in angular deviation (in milliradians) between the right and left eye positions were calculated to determine binocular convergence, divergence, and dipvergence (vertical) as a function of azimuth angle for each visor. The angular deviation between the two eye positions was within acceptable limits for eye convergence, divergence, and dipvergence.

Transmissivity

The photopic transmissivities (%) of various exterior scene objects as seen through the PIHM visors and clear visor are listed in Table 3. The transmission of the PIHM visors varied from 88-90%, while the transmission of the standard clear visor was 96%. The difference in transmission between the clear visor and PIHM visors can be considered negligible.

Table 3. Photopic Transmission (%) of various exterior scenes through PIHM and standard clear visor.

	VISOR			
OBJECT	SMALL PIHM	MED PIHM	LARGE PIHM	CLEAR
Trees on Hill	90.1%	90.2%	88.2%	95.9 %
Grass on Hill	90.1	90.3	88.3	95.9
Pavement	90.1	90.3	86.3	95.9
Blue sky	90.1	90.2	88.3	95.9
Horizon haze	90.1	90.2	88.3	95.9
Gravel on rooftop	90.1	90.3	88.3	95.9
Grass field	90.1	90.2	88.3	95.9
Cream building	90.1	90.3	88.3	95.9
Red brick building	90.2	90.3	88.3	95.9
Dark brown roof	90.2	90.3	88.3	95.9

CONCLUSIONS

This evaluation was designed to examine the compatibility of ANVIS night vision goggles with the PIHM system. Both field and laboratory evaluations indicated that the integration of ANVIS with the PIHM did not result in any significant compatibility problems. However, both evaluations demonstrated the importance of following proper PIHM donning procedures and careful adjustment of the ANVIS to ensure optimal performance. It is recommended that proper training procedures be developed and adopted for using PIHM in combination with ANVIS.

The RAF Institute of Aviation Medicine Proposed Helmet Fitting/Retention System

John V Barson and Roger J Croft
Royal Air Force Institute of Aviation Medicine
Farnborough Hampshire GU14 6SZ
United Kingdom

SUMMARY

The role of the protective flying helmet has rapidly expanded from being a device for protecting the flyer from impact and noise hazards to include mounting platforms for vision enhancement devices as well as target sighting and designation systems that requires a greater degree of helmet stability and may result in greater physical exertion by the wearer. Many of the personnel now involved in the operation of these various systems are not pilots and may only fly in the aircraft for specific missions. Additionally, the requirement to wear chemical defence respirators make the fitting and refitting of these helmets time and manpower consuming.

This paper describes a new helmet fitting/retention system developed at the RAF Institute of Aviation Medicine that has the potential to provide a quick and effective method of rendering a good, safe, and stable helmet fit using a minimum number of helmet sizes. The fitting/retention system also provides a relatively consistent eye position for optical systems and allows rapid donning of a chemical defence respirator. Additionally, the fitting/retention system can be used for a one-size-fits-all helmet while retaining all the above mentioned features for personnel who are only flying on specific missions and normally are not issued a flight helmet.

The fitting/retention system uses a simple series of straps and an occipital pusher plate to accommodate head length. By suspending the occipital pusher plate from the upper aspect of the rear of the helmet, anterior rotation both in flight and during a crash is prevented. The height adjustment is provided by a specifically shaped and contoured pad in the top of the helmet which contacts the head in such a way and over a sufficiently large area to correctly position the helmet vertically on the head for a wide range of pupil-vertex heights.

INTRODUCTION

Since the introduction of protective flying helmets early this century, there has been an ongoing development of various systems for their fitting and retention. These systems use a variety of fitting mechanisms including many arrangements of straps and/or pads and "high tech" materials such as expanded foam and thermal plastic formed liners. Additionally, there have been many sizing schemes used to determine the number and range of helmet sizes required to fit the designated population. These systems provide a varying degree of fit from very good to very poor. The fitting technique also often requires significant amounts of manpower and time for adjustment and maintenance.

The expansion of the protective helmet's role from impact and noise protection to include mounting platforms for vision enhancement devices as well as target sighting and designation systems requires a greater degree of helmet stability than current helmet fitting/retention systems may be capable of providing. The problems of increased weight and changes in the helmet's centre of gravity that often accompany the use of these systems must be considered since they may require greater physical exertion by the wearer causing early fatigue and perhaps decrease the length of a mission.

DESIRABLE FITTING/RETENTION CHARACTERISTICS IN FLYING HELMETS

The complexity of both current and future sighting and designation systems, as well as other vision augmenting and data displays generates the requirement that a helmet's fitting and retention system provide a quick and effective method of rendering a good, safe, and stable helmet fit in a minimum number of helmet sizes. The fitting/retention system must also locate the helmet mounted systems at the optimum eye position and allow the rapid donning of a chemical defence respirator without needing to be adjusted. Additionally, the fitting/retention system must be adjustable by the wearer and easily refitted by the wearer in the field where maintenance personnel may be scarce.

DESCRIPTION OF THE RAF IAM FITTING/RETENTION SYSTEM

The fitting/retention system (Figure 1) consists of a simple series of two horizontal straps (a1 and a2) and a contoured occipital pusher plate (b1) to accommodate head length. The lower of the two horizontal straps (a1), is continuous with the chinstrap. The upper horizontal strap (a2) is adjusted by pulling the ends of the straps, which in this version of the helmet are located as straps on the outside of the helmet. The occipital pusher plate is suspended by two straps (c1 and c2) from the upper aspect of the rear of the helmet. The brow pad (d1) is constructed from open cell foam with a leather cover. The height adjustment is provided by a specifically shaped and contoured crown pad (e1) in the top of the helmet that contacts the head in such a way and over a sufficiently large area so as to

correctly position the helmet vertically on the head over a wide range of pupil-vertex heights.

OPERATION OF THE FITTING/RETENTION SYSTEM

The helmet is donned by placing the forehead into the helmet against the forehead pad and rotating the helmet down over the head. The chinstrap is fastened and two fingers are hooked over the chinstrap and pulled downward. This action pulls the lower horizontal strap bringing the lower aspect of the occipital pusher forward against the back of the head compressing the brow pad with the forehead. The chinstrap is then tightened it contacts the skin. The upper horizontal strap is tightened by pulling the two external straps on the sides of the helmet. The upper horizontal strap pulls the upper aspect of the occipital pusher late forward against the back of the head. Additionally, the upper horizontal strap runs around the outside of the ear capsule and when tightened, pulls the ear capsule against the side of the head. The ear capsules are attached to a free sliding cross strap system that allows them to move in three dimensions while automatically locating over the ears. This completes the donning procedure. The helmet is removed by unfastening the chinstrap and rotating the helmet forward off the head.

FITTING/RETENTION SYSTEM MECHANISMS

A primary aim of most helmet fitting/retention systems is to centre the head in the helmet. This is achieved by adjusting the front, rear, and sides of the helmet in or out from the head. The height is adjusted by raising or lowering the helmet on the head. These adjustments are usually made bv various combinations of straps, pads, or other filling materials. The weakness of centering the helmet on the head is that variations in head length and the recess of the eyes in the head can result in very large differences in the distance from the eye to the exit pupil plane of a helmet mounted sighting or display system. This problem of variation in eye recess is further complicated by the centering type fitting system's adjustment mechanisms effectively positioning the head either forward or rearward as part of the fitting process. A result of this wide range of eye depths is that field-of-view may be compromised. Amelioration of this problem usually requires multiple helmet sizes to fit the user population. The number of sizes of helmet may be fairly large in order to achieve a good and stable fit in the user population. As the number of sizes increases, the sighting or display system may require modification to conform to the external geometry of the helmet. Both the increased number of helmet sizes and changes to the sighting or display system necessitated by the helmet geometry can severely tax logistics systems required to supply replacement helmets and repair parts, and may also result in increased unit cost.

The RAF IAM fitting/retention system uses the contact point between the forehead and the brow pad as a fixed reference position around which the rest of the helmet is located. The occipital pusher plate presses the forehead into the brow pad of the helmet. By fixing the forehead against the brow pad, it is possible to eliminate the eye position variable created by the forehead standoff in a centering type helmet fitting system leaving the depth of the eye in the head as the only variable to be considered in any optical system's adjustment mechanism. Therefore, the optical system's adjustment mechanism can have smaller distances to travel to accommodate various individuals.

The head length adjustment is achieved by the occipital pusher plate suspended internally by two vertical straps from the upper aspect of the rear of the helmet. The plate is brought forward by the tightening of two horizontal straps. This forward movement of the plate compresses the brow pad foam reducing the potential for dynamic overshoot from the open cell foam. By suspending the plate from two vertical straps and having the chinstrap connected to the lower horizontal strap, anterior rotation is prevented both in flight and during a crash. The action which prevents the rotation is a result of the upward and forward rotation of the helmet during a crash causing the chinstrap to tighten on the chin. Because the chinstrap runs around the occipital pusher plate, the tightening of the chinstrap pulls the plate more firmly to the back of the head. With the occipital pusher plate pulled firmly onto the back of the head, the two vertical straps prevent the helmet from rotating forward.

The height adjustment of the helmet on the head is achieved automatically by a rectangular shaped composite crown pad constructed of expanded polyethylene and open cell foam. The expanded polyethylene pad is of a constant thickness over the entire length and width of the pad and is tailored to the size and shape of the helmet shell. The open cell foam is layered on the expanded polyethylene and is nearest the head. The open cell foam is a maximum of 6 mm thick to prevent dynamic overshoot. The entire head facing surface of the composite pad is covered with a brushed nylon cloth. The composite pad runs over the interior surface of the helmet impact liner from just above the brow pad in the front of the helmet to a point in the rear of the helmet that corresponds in height to the top of the face aperture opening. The width of the pad in a large helmet shell is limited to 140 mm so that it does not reduce the head breadth fitting capacity of the helmet. The pad width may be less in smaller helmet shells.

The mechanism for the automatic height adjustment that allows a wide range of pupil-vertex dimensions to be accommodated has not been completely defined. It appears to be the result of a combination of the head being pushed to the front of the helmet by the occipital pusher plate and the contour, shape, and composition of the crown pad. The forehead is fixed on the brow pad. The crown

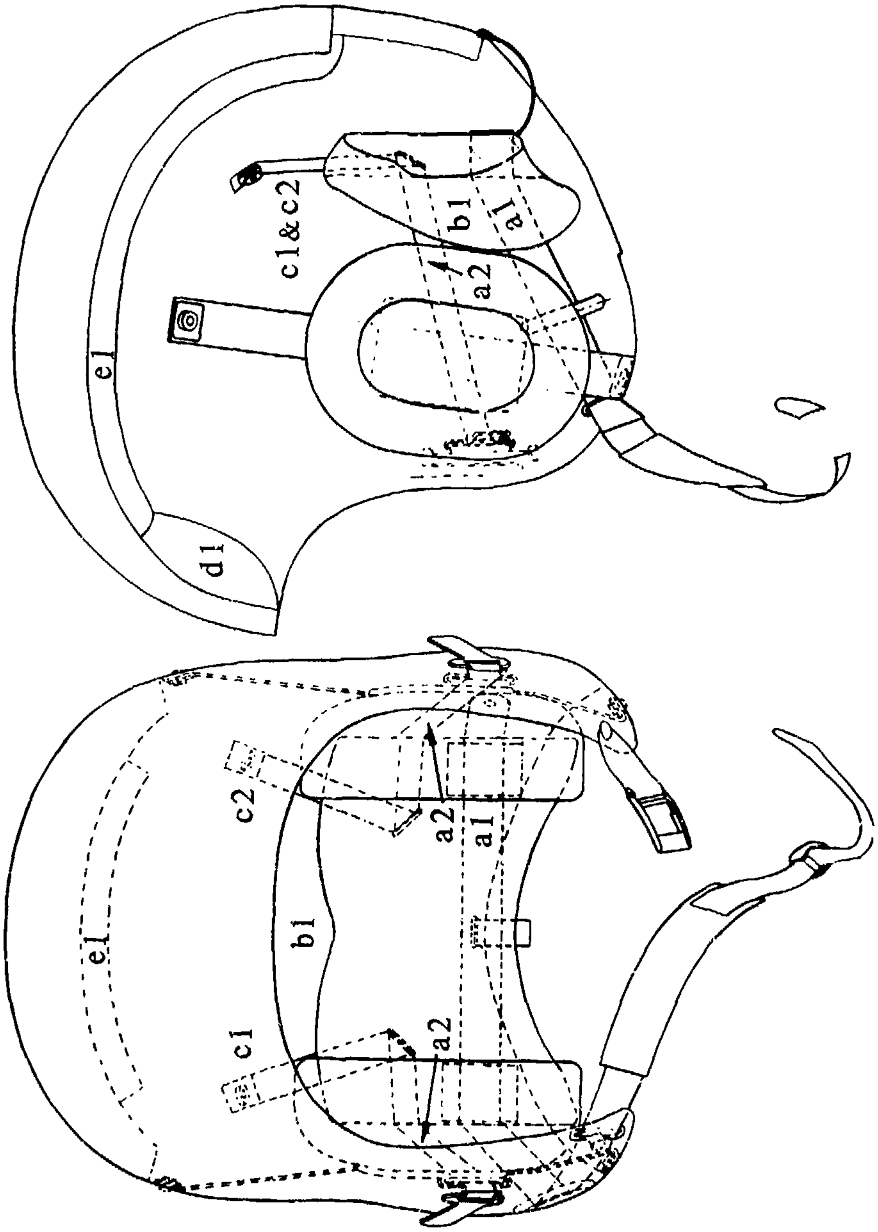

FIGURE 1 Schematic of the RAF IAM Helmet Fitting/Retention System

pad then comes into contact with the upper part of the forehead. This crown pad contact extends superiorly over the sagittal suture region of the head. The open cell foam compresses providing a slight cushion effect over any protuberances of the skull and fills in any resulting gaps. The expanded polyethylene has enough elasticity to conform slightly to the longitudinal and coronal curvatures of the head while retaining its impact protective properties. The surface area contact of the crown pad on individuals with different head sizes varies to some degree. However, it is believed that the crown pad, due to its contour, shape, and composition, provides a self positioning minimum area of contact exceeding the 476 square cm of contact area in the Mark 10 RAF Aircrew Helmet. This feature of conforming to the contours of the skull provides automatic height adjustment.

FITTING CAPABILITIES OF THE RAF IAM FITTING/RETENTION SYSTEM

The prototype RAF IAM fitting/retention system was installed in a Mark 4B aircrew helmet. Internal measurements were made of this helmet to assess the theoretical maximum and minimum head length and breadth dimensions that might be accommodated. A comparison of the theoretical head dimensions accommodated by the RAF IAM fitting/retention system in the large size Mark 4B aircrew helmet and the helmet manufacturer's recommended head dimensions for accommodation in the standard 5 sizes of Mark 4B aircrew helmets is shown in Table 1.

Table 1

Comparison of the Theoretical Head Dimensions Accommodated by the RAF IAM Fitting/Retention System in a Large Mark 4B and the Helmet Manufacturer's Recommended Head Dimensions for Accommodation in the Standard 5 Sizes of Mark 4B Aircrew Helmets

Helmet Type and Size	Head Breadth (mm)	Head Length (mm)
RAF IAM Large Mark 4B	120 to 175	188 to 222
Standard Mark 4B		
Small	142 to 159	180 to 199
Medium	147 to 164	186 to 205
Medium/Broad	159 to 175	186 to 205
Medium/Long	147 to 164	199 to 218
Large	159 to 175	199 to 218

The helmet sizing scheme used for determining the number of helmet sizes for the Mark 4B aircrew helmet is based upon data from the Anthropometric Survey of 2000 Royal Air Force Aircrew, 1970/1971 (Ref 1). By using 5 sizes of helmets, the standard Mark 4B aircrew helmet accommodates the 1st through the 99th percentile head breadth and length dimensions from that survey. By comparison, the RAF IAM fitting/retention system installed in a large Mark 4B aircrew helmet using the fit and stability assessment method describe below, has the potential to fit a range of head dimensions smaller than the 1st percentile up to the 99th percentile in head breadth and from the 5th to greater than the 99th percentile in head length using only one size of helmet.

A limited fitting evaluation was performed to assess the automatic height adjustment capability of the RAF IAM fitting/retention system. A total of four subjects were used representing the 3rd through the 99th percentile for pupil-vertex height as found in the 2000 aircrew survey. The results of the evaluation are shown in Table 2.

Table 2

Limited Evaluation of the RAF IAM Fitting/Retention System's Automatic Height Adjustment for 4 Subjects Demonstrating the System's Ability to Maintain a Near Constant Pupil to Top of Helmet Face Aperture Distance

Subject No	Pupil-Vertex Height	Pupil-Top Face Aperture Distance (mm)
1	97 mm (3rd percentile)	58
2	106 mm (25th percentile)	51
3	112 mm (50th percentile)	50
4	132 mm (99th percentile)	55

The difference in the pupil to the top of the helmet face aperture distance is eight millimetres for subjects with pupil-vertex heights that range from 97 mm (3rd percentile) to 132 mm (99th percentile). While many helmet fitting systems can achieve a relatively consistent eye position by the manipulation of their fitting systems, the RAF IAM fitting/retention system required no additional personnel, tools, or procedures other than the normal donning procedure. All subjects were able to completely don and fully adjust the helmet in less than 30 seconds.

STABILITY AND ASSESSMENT OF HELMET FIT

Since the development of the prototype, over fifty individuals in addition to those in the limited evaluation have worn the helmet. Each person who wore the helmet was examined to determine if the helmet provided the same level of fit and stability as the standard Mark 4B aircrew helmet. The procedure for this evaluation is described in the Ministry of Defence Air Publication (AP) 108F-0214-12 Chapter 1.1. The evaluation consisted of checking for movement and displacement of the helmet on the wearer's head when external hand pressures were applied. To check for head length fit, pressure was applied to the rear of the helmet and the forehead-brow pad region was observed for a gap appearing indicating movement. The ear capsule seal was evaluated by applying pressure to first one side, then the other side of the helmet and while watching for the ear seal lifting off from the side of the head. Anterior-posterior rotation was checked by placing a hand on each side of the helmet and attempting to rotate the helmet forward. Some scalp movement is encountered with this procedure, however, the helmet should not slide over the scalp. Using this technique for evaluation of fit indicated that a few individuals with small head lengths had some slight gaping in the brow pad region. However, the vast majority achieved a good and stable fit. All individuals achieved good ear seal as defined by the Air Publication.

It was expected that some individuals with short head lengths might have some fitting difficulty because of the length of this dimension. The RAF IAM fitting/retention system when fitted into a large Mark 4B helmet normally accommodates at minimum a head length of 188 mm. The small number of individuals who had some forehead-brow pad gaping were usually found to have head lengths significantly less than 188 mm. This observation will be more closely examined during a future evaluation when the RAF IAM fitting/retention system is installed in a medium size Mark 4B helmet.

The helmet was also evaluated on the deceleration track. The helmet was adjusted to the head a Hybrid III dummy which was seated upright and subjected to 14 +Gx acceleration. The helmet was filmed during the acceleration using high speed video. The helmet did not appear to move or lift from the dummy's head during the test. With night vision goggles fitted, the degree of helmet rotation at 10 +Gx acceleration was less than that observed with a small size Mark 4A helmet on the same headform configuration.

CURRENT STATUS

The RAF IAM Helmet Fitting/Retention System has currently been installed in the large size Mark 4A, Mark 4B, and Mark 10A Aircrew Helmets. A variant of the system is currently in a field trial of the Type 15 Army Helicopter Passenger Helmet. The Type 15 helmet was used by both passengers and aircrew in the Persian Gulf War for Operation Granby. A Ministry of Defence Patent Application has been submitted for this system (Ref 2).

Future work on the RAF IAM Helmet Fitting Retention System will extend the assessment of the system in other helmet types including those helmets used by other NATO Forces.

CONCLUSIONS

The RAF IAM Helmet Fitting/Retention System has the potential to provide a quick and effective method of producing a good, safe, and stable helmet fit in a minimum number of helmet sizes over a wide range of head dimensions. The fitting/retention system automatically provides a relatively consistent eye position for helmet mounted visual display and sighting systems for a wide range of pupil-vertex heights. It allows for the rapid donning of a chemical defence respirator and is adjustable by the user in the field without the use of tools. Preliminary observations indicate that the retention capability of the helmet is excellent. Additionally, the fitting/retention system can be used for a "one-size-fits-all" helmet for personnel who are only flying on specific missions and normally are not issued a flight helmet.

REFERENCES

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REPONSE BIOMECANIQUE DE LA TETE AUX ACCELERATIONS+ GZ: INTERET POUR LES ETUDES EN SIMULATEUR DE COMBAT.

A. LEGER*, P. SANDOR, C. BOURSE, A. ALAIN
Laboratoire de Médecine Aérospatiale
Centre d'Essais en Vol
F-91228 BRETIGNY SUR ORGE

ODSA/STR
Centre d'Electronique de l'Armement
F-35170 BRUZ

RESUME : Les simulateurs à base fixe ne peuvent restituer l'effet des contraintes biomécaniques résultant des accélérations, ce qui peut poser problème pour l'interprétation des études de viseur de casque. Une étude en centrifugeuse sur la réponse biomécanique de la tête lors d'une tâche de visée a été conduite pour différentes pentes de variation d'accélération (0.3, 0.6 et 1 G.s-1). L'accélération terminale en plateau était dans tous les cas de + 5 Gz. Les résultats obtenus montrent que la stabilité de visée (Ecart Quadratique Moyen) sur une cible collimatée à l'infini varie de 0.8° à 0.3 $G.s^{-1}$ jusqu'à plus de 2° à 1 $G.s^{-1}$. Les caractéristiques de la réponse biomécanique de la tête ont été analysées. Des recommandations pratiques pour la modélisation de l'effet de la contrainte biomécanique lors des études en simulateur de combat sont avancées.

1. INTRODUCTION

L'évolution de l'armement et des systèmes conduit actuellement à prévoir l'utilisation du viseur de casque comme l'un des moyens de dialogue du pilote avec le système d'armes des avions de combat modernes. La validation de ce concept a très largement bénéficié des études amont réalisées en simulateur de combat (1) qui constitue maintenant une étape fondamentale pour l'optimisation de l'interface Homme/Système. Les simulateurs de combat à base fixe ne peuvent cependant restituer physiquement les contraintes d'environnement du combat aérien, en particulier les accélérations. L'effet biomécanique de celles-ci sur le système tête-cou constitue pourtant une contrainte dimensionnante pour le pilote en affectant la stabilité de la visée lors des manoeuvres de combat.

Les résultats obtenus en simulation doivent donc faire l'objet d'une analyse critique sur ce point et, en pratique, les essais en vol peuvent seuls amener une réponse définitive prenant en compte l'effet des accélérations. Le recours à des essais coûteux et souvent difficiles à mettre en oeuvre est tout a fait essentiel dans le cadre de la validation terminale d'un concept, lorsque les bases d'études amont sont bien établies. Pour ce qui concerne les aspects physiologiques, l'expérience montre qu'il est habituellement difficile d'exploiter et d'analyser finement les résultats obtenus lors d'essais en vol si l'on souhaite comprendre les mécanismes qui affectent la performance du pilote. Ainsi, si les performances obtenues lors de tels essais ne sont pas d'emblée celles requises pour la mise en oeuvre correcte du système, il est parfois difficile de faire la part de ce qui revient à l'homme ou au système lui même. Dans ces conditions, il est peu aisé, éventuellement coûteux et parfois impossible d'entreprendre des actions correctrices réellement efficaces.

Un premier objectif des études en centrifugeuse humaine est d'apporter des réponses précises, forcément de portée limitée mais peu coûteuses, qui contribueront à l'analyse des résultats obtenus lors des essais en vol. L'utilisation de résultats d'essais en centrifugeuse pour tenter d'améliorer la validité des résultats obtenus en simulation de combat constitue une approche moins classique.

Pour l'utilisation d'un viseur de casque, le problème du contrôle en stabilité de la tête sous facteur de charge se pose sous plusieurs aspects. L'un d'entre eux, le contrôle moteur fin, concerne essentiellement les performances de désignation qui peuvent être attendues d'un viseur de casque. D'assez nombreuses études, récemment revues et complétées par WELLS et GRIFFIN (7), réalisées dans de conditions statiques ont été consacrées à ce sujet. Il existe également dans la littérature des exemples d'études réalisées en vol avec ce but (2). Enfin, des résultats obtenus en centrifugeuse ont déjà été présentés par ailleurs (3,4,5). Ils montrent, entre autres, que les variations d'accélérations amènent des perturbations de la stabilité beaucoup plus importantes que les accélérations + Gz établies.

L'étude présentée avait pour objectif de caractériser quantitativement la réponse biomécanique du système tête-cou en fonction de la variation d'accélération selon l'axe Z (+Gz). Ces caractéristiques étant identifiées, on peut alors envisager d'appliquer les résultats au problème de la simulation de combat.

*Now at SEXTANT-Avionique, Rue Toussaint Castros, BP 91, 33166 St Medard en Jalles, Cedex.

2. METHODES

L'expérimentation a été conduite dans la nacelle universelle de la centrifugeuse du Laboratoire de Médecine Aérospatiale.

2.1 Dispositif expérimental

Le dispositif expérimental a été décrit en détail par ailleurs (3,4). Il est organisé autour d'une maquette géométrique du démonstrateur "Rafale A".

Un viseur de casque électro-optique THOMSON CSF permet la détermination de la direction de la visée par rapport à une référence de zéro établie à l'initialisation au moyen d'un collimateur fixe tête haute. Il permet de déterminer les mouvements de la tête avec une précision de 0,5° pour les angles et d'environ 1 mm pour les translations. La cadence de mesure est de 20 points par seconde.

Ce viseur est monté sur un casque GUENEAU 458 modifié pour la circonstance. Le poids total du dispositif est de 1380g. La tenue du casque est assurée par un habillage interne adapté pour chaque sujet. Un masque inhalateur, dépourvu de la chenille d'alimentation, complète la contention. Un équipement de protection anti-G est utilisé systématiquement.

Trois accéléromètres montés sur un trièdre, placés à proximité de la tête du sujet, permettent d'enregistrer les accélérations sur les trois axes nacelles X, Y, Z.

Le dispositif d'acquisition des données numériques et analogiques utilise un calculateur DEC LSI 11-73. Les logiciels d'expérimentation et d'exploitation sont écrits en FORTRAN IV avec des routines Macro 11. Ils fonctionnent sous un système d'exploitation RT-11 SJ pour l'acquisition de données et la gestion de l'expérimentation et sous TSX pour l'exploitation différée.

2.2 Protocole expérimental

2.2.1 Sujets

Neuf sujets volontaires ont participé à l'expérimentation. Ils ont été recrutés parmi les parachutistes d'essais et divers personnels du Centre d'Essais en Vol. Tous les sujets possédaient une expérience préalable des essais en centrifugeuse.

2.2.2 Installation du sujet - consignes d'expérience

Les consignes utilisées au cours de cette expérimentation étaient très simples. Le sujet devait maintenir une visée casque la plus stable possible sur un point situé à l'infini, matérialisé par le réticule du collimateur fixe utilisé pour l'initialisation. Il s'agissait donc d'une visée horizontale (site et gisement nuls) effectuée sans que la tête ne repose sur l'appui-tête.

2.2.3 Déroulement des essais

Chaque sujet effectuait successivement trois essais. Chaque essai constituait en une montée en accélération jusqu'à un plateau terminal de + 5 Gz. Trois pentes de mise en accélération (d(G)/dt) étaient explorées : 0,3, 0,6 et 1 Gs^{-1}. Les deux premières conditions étaient obtenues avec un lancement électrique de la centrifugeuse. Pour la pente à 1,0 G/s le lancement était effectué en mode catapulte.

De façon à éviter un effet lié à l'ordre de présentation des différents essais, le plan expérimental était organisé selon un carré latin 3 X 3 avec 3 répétitions (9 sujets).

Entre chaque essai, un temps de repos de quelques minutes était accordé au sujet. Des essais préliminaires avaient montré que cette procédure était bien tolérée et n'entraînait pas de fatigue excessive.

2.3 Acquisition et traitement des données

Après chaque essai, les données brutes de site et de gisement de la visée étaient affichées à l'écran sous forme graphique, de façon à contrôler immédiatement la qualité des résultats.

L'exploration des résultats a conduit à la mise en oeuvre de deux types de traitement.

2.3.1 Représentation graphique

Les données des différents sujets ont été rassemblées de façon à obtenir des graphiques comparatifs, en fonction du temps, pour les différentes pentes de mise en accélération.

A partir de ces données l'écart quadratique moyen de visée en site et en gisement a été calculé, à partir de 2 G jusqu'à l'arrivée en plateau à 5 G.

2.3.2 Analyse spectrale

Une analyse spectrale a été conduite sur les signaux de site et de gisement obtenus lors des essais. Cette analyse a fait appel à une routine de transformée de Fourier rapide.

La stimulation appliquée sur le système tête cou n'est ni périodique ni constante. De façon à prendre en compte le facteur variation d'accélération et le facteur niveau d'accélération dans la description du phénomène une analyse spectrale à trois dimensions a été utilisée (Temps, Fréquence, Puissance).

3. RESULTATS

Nous aborderons successivement l'examen des données brutes, l'évolution des écarts quadratiques moyens de visée selon les différentes conditions, puis les résultats de l'analyse spectrale.

3.1 Examen des données brutes

Les résultats obtenus sont présentés sous forme graphique, pour chaque sujet et chaque variation, aux figures 1, 2, et 3 pour la visée en site . Les tracés en gisement ne sont pas présentés ici. Ces résultats portent sur 8 sujets. L'un des sujets a dû être éliminé du traitement en raison d'un problème d'ordre technique (décalage de la lame dichroïque du collimateur de casque).

L'examen des données brutes présentées aux différentes figures permet de juger qualitativement de l'effet des différentes pentes. On note l'existence de perturbations de la visée, d'allure pseudo-périodique.

Par rapport à la visée de référence, où la stabilité est meilleure que 0,5° pour l'ensemble des sujets, les perturbations sont présentes même avec les mises en accélération à pente faible (0,3 $G.s^{-1}$). On remarque une très grande variabilité selon les sujets, aussi bien dans l'amplitude que dans la forme des perturbations.

On constate, en examinant comparativement les tracés, que l'apparition des oscillations est plus tardive avec la pente la plus faible (fig. 1, 2). Ce fait peut être interprété comme l'existence d'un effet de seuil lié à la valeur instantanée de G.

Pour la pente la plus forte (1 $G.s^{-1}$, fig. 3) il existe au début de chaque tracé une perturbation en pic de grande amplitude (supérieure à 5°). Cette perturbation est liée au mode de démarrage de la centrifugeuse (catapulte) qui engendre un transitoire d'accélération selon l'axe X. Ce transitoire atteint une amplitude de +0,5 à 0,6 Gx.

Il existe une très grande variabilité interindividuelle quant à l'amplitude et à la fréquence des oscillations de la visée pendant la montée en accélération. Pour le sujet n° 7 qui obtient des résultats médiocres, quelles que soient les pentes, l'amplitude maximale crête à crête des perturbations atteint 4° dès 0,3G par seconde. Elle passe à 10° avec la pente à 1G/s. Les tracés des sujets 2 et 3 montrent au contraire une stabilité relativement bonne. Toutefois, à 1 $G.s^{-1}$, on observe des perturbations dont l'amplitude crête à crête atteint 4 à 6°.

L'arrivée en plateau d'accélération à 5G (pour les essais à 0,6 $G.s^{-1}$ et 1 $Gs.^{-1}$) se traduit pour la plupart des sujets par un retour à une visée beaucoup plus stable. Les variations observées ne dépassent alors pas 1° d'amplitude.

3.2 Ecart quadratique moyen

Les valeurs des écarts quadratiques de visée en site et en gisement (sur 8 sujets) pour les différentes pentes, sont présentées à la figure 4. Comme l'indiquent les valeurs présentées, il existe une forte variabilité interindividuelle.

On constate, aussi bien en site qu'en gisement, que ces valeurs varient peu avec les pentes à 0,3 et 0,6 $G.s^{-1}$. Par contre le lancement à 1 $G.s^{-1}$ se traduit par une augmentation plus importante de l'écart quadratique de visée. Celui-ci dépasse 2° en site, lorsque l'on s'intéresse à la moyenne sur l'ensemble des sujets. En excluant le sujet n° 7 de ce calcul de moyenne, l'écart quadratique de visée moyen atteint encore 1,7° (66 % des mesures entre ± 1,7° par rapport à la valeur de consigne).

3.3 Analyse spectrale

Les résultats obtenus en soumettant les signaux de visée à l'analyse spectrale se sont révélés décevants, sans doute en raison d'une technique d'analyse mal adaptée.

En effet les spectres des puissances obtenus montrent une répartition relativement constante en fonction de la fréquence. Dans la plupart des cas, on observe entre 1 et 2 Hz une bande dont l'amplitude est seulement très légèrement supérieure à celle du bruit de mesure.

4. DISCUSSION

Le domaine de variation d'accélération utilisé lors de cette étude constitue le premier point de cette discussion. En effet, il demeure relativement loin des

possibilités des avions de combat modernes susceptibles de recevoir un viseur de casque. Nous aborderons ensuite le problème de la stabilisation de la tête, sous ses aspects biomécaniques et de contrôle moteur. Le dernier point sera constitué par l'application pratiques aux études en simulateur de combat qui peut être envisagée à partir des résultats obtenus.

4.1 Domaine de stimulation

Les variations d'accélération (d(G)/dt) utilisées pour stimuler de système tête-cou lors de l'expérimentation peuvent apparaître relativement faibles par rapport au domaine d'un avion comme le Mirage 2000 ou le Rafale. Selon les données obtenues au CELAR lors de campagne de simulation de combat avec viseur de casque, on peut se rendre compte que les situations étudiées en centrifugeuse sont dans un domaine relativement réaliste d'utilisation du viseur (fig 5).

En effet, sur 8 vols sélectionnés on constate que dans près de 93 % des cas, le viseur est utilisé avec une variation de facteur de charge inférieure à 2G/S (près de 48 % en facteur de charge constant). Par ailleurs on retrouve un certain nombre de notions déjà évoquées antérieurement montrant une utilisation préférentielle entre +1,5 et +2,5 G, avec des pics secondaires à +3,5, 5 et 8 G (fig 6).

Compte tenu de ces données, on peut finalement considérer que le domaine couvert par l'étude en centrifugeuse (de 0,3 à 1 Gs^{-1} avec un plateau à 5G) s'applique relativement bien à une situation plus opérationnelle, réalisée en simulation de combat.

4.2 Aspects fondamentaux des mécanismes de stabilisation

Relativement peu d'études ont été consacrées à l'effet des perturbations dynamiques sur la stabilisation en position de la tête. Parmi celle-ci, l'étude pilote réalisée par VIVIANI et BERTHOZ (6) amène des données intéressantes pour notre propos. Les auteurs se sont particulièrement intéressé à la dynamique du système tête-cou en réponse à des petites perturbations de force appliquée dans le plan sagittal de la tête.

Les auteurs ont ainsi montré qu'en mode sinusoïdal au dessous de 2 Hz, lorsque le sujet résiste d'une manière active à la force appliquée, la réponse de la tête montre une distorsion très importante par rapport à la stimulation d'entrée. En revanche, au dessus de 2 Hz la réponse devient presque linéaire et le résultats suggèrent que l'ensemble tête-cou se comporte comme un système quasi-linéaire du second ordre avec 2 degrés de liberté. Cette étude met en evidence que l'on ne peut se baser sur des données statiques (par exemple la force maximale développée par les muscles du cou) pour prédire le comportement dynamique d[illegible]e. En [illegible] des forces relativement faibles variant dans le temps peuvent indu[illegible] déplacement [illegible] tête non négligeable.

En basse fréquence, l'annulation com[illegible] des mouvements de la tête n'est obtenue qu'en dessous de 0,4 Hz, dans les conditions expérimentales utilisées par les auteurs.

Ces données sont à rapprocher des observations effectuées lors des essais en centrifugeuse.

L'étude en centrifugeuse amène à considérer l'application de forces selon l'axe Z du système tête-cou, variant dans un domaine de temps (5 à 12 s) largement supérieur à celui utilisé par VIVIANI.

En revanche les forces appliquées ont une amplitude beaucoup plus grande (fonction de la résultante des forces d'inertie appliquées au centre de gravité de la tête). Dans le cas de l'étude en centrifugeuse, la force à prendre en compte, est la modification du poids de la tête équipée (soit près de 7,5 kg) en fonction de l'accélération résultante (5 maximum). Ceci correspond donc approximativement à une force de 300 N, très supérieure à celles envisagée plus haut (15 N au maximum).

Les valeurs de sortie considérées dans l'étude en centrifugeuse sont les variations angulaires de la ligne de visée, sur une cible située à l'infini. L'étude précédente considère en fait le déplacement total de la tête en réponse à la stimulation. Sur un plan fondamental, il aurait donc fallu prendre en compte la mesure des translations de la tête afin de mettre en évidence une réponse harmoniquement liée à la stimulation. Cette réponse ne constitue cependant pas l'essentiel du problème du viseur de casque, puisqu'elle n'intervient pas sur la direction de la visée, lorsque celle- ci s'effectue à l'infini.

La variable de sortie utilisée en centrifugeuse prends ainsi une dimension plus "opérationnelle" (maintien de la capacité de désignation avec rétro-action-visuelle) que biomécanique. On peut alors considérer que l'effet lié à la rétro-action visuelle, qui ne contribuait pas significativement aux résultats obtenus par VIVIANI et BERTHOZ, est sans aucun doute prédominant dans l'étude en centrifugeuse.

Ceci est clairement démontré par les résultats issus d'une étude complémentaire effectuée ultérieurement. Trois conditions de vision ont été alors utilisées : Rétroaction visuelle (matérialisation de la position de la tête), vision sans rétroaction, sans vision (maintien de la visée stable sur une cible imaginaire). Le comportement oscillatoire de la tête est en effet liés à la condition de rétroaction visuelle alors que les deux autres conditions conduisent à des réponses plus directes par rapport à la stimulation.

Ces éléments montrent la difficulté existante dans la transposition directe des résultats d'une expérimentation à l'autre. En particulier, on peut légitimement faire l'hypothèse que l'amplitude maximale des forces observées en centrifugeuse modifie fortement les caractéristiques de réponse du système tête-cou.

Certaines similitudes peuvent cependant être relevées, en particulier pour ce qui concerne la réponse observée avec l'accélération + Gx en début de catapultage. Dans cette condition, avec une fréquence initiale de stimulation élevée, la réponse du système est, selon toute vraisemblance, très liée à l'état de tension de la musculature du cou et non à une commande d'opposition au déplacement. Les variations interindividuelles dans l'amplitude de la réponse peuvent alors être attribués aux caractéristiques des paramètres viscoélastiques du système. On peut alors retrouver une analyse des mécanismes identique à celle proposée par VIVIANI et BERTHOZ.

Dans le contexte fonctionnel de la coordination de l'oeil et de la tête, il est logique de considérer que, sous l'effet de forces extérieures, la tête n'assure qu'une stabilisation grossière alors que l'oeil est responsable des ajustements fins conduisant à l'obtention d'une vision nette. Ces considérations s'insèrent d'une manière cohérente avec les données fondamentales disponibles sur ce sujet. Ceci amène à envisager que les mécanismes de stabilisation de la tête, en présence de perturbations variant dans le temps, ne soient pas naturellement bien adaptés au maintien d'une position précise fixe dans l'espace. Dans ces conditions l'utilisation d'un viseur de casque qui, par principe, supprime la possibilité d'ajustement fin par le mouvement de l'oeil, ne peut conduire à une désignation précise lorsque l'accélération varie. En revanche, dans des conditions statiques, lorsque les forces appliquées ne changent pas dans le temps, les mécanismes de stabilisation de la tête retrouvent leur efficacité. Une dégradation de la performance peut alors être attribuée à un effet direct des forces sur l'effecteur, c'est-à-dire une saturation des possibilités mécaniques du système ostéoarticulaire et musculaire du cou. Il faut remarquer ici que cette situation n'a pas été rencontrée dans le domaine d'accélération étudié (jusqu'à +5 GZ) et pour l'équipement de tête utilisé.

4.3 Application pratique à la simulation de vol

Comme l'indique l'ensemble des résultats obtenus, il faut s'attendre à une dégradation notable des possibilités de désignation par un système porté par la tête, lors des variations d'accélération. Il faut remarquer ici que les essais ont été effectués avec la tête en position de référence (visée horizontale) et qu'une visée sur un point excentré amène généralement une dégradation supplémentaire (6).

Il semblerait donc judicieux d'introduire cette notion dans les études menées en simulateur de combat. L'utilisation d'un signal de bruit surajouté aux mesures provenant du viseur de casque, fonction de G et de d(G)/dt, constitue une solution possible.

Les résultats obtenus avec l'analyse de fréquence ne permettent pas d'identifier précisément les caractéristiques de fréquence. La technique d'analyse et la faible durée des expérimentations sont de toute évidence mal adaptées à ce propos. Il est cependant possible de proposer des recommandations définissant approximativement les caractéristiques d'un tel bruit :

- bande étroite en basse fréquence (F < 10 Hz) avec une dominante entre 1 et 2 Hz.

- l'énergie du signal pourrait être évaluée par une interpolation réalisée à partir des valeurs d'écart quadratique moyen obtenues pour les différents d(G)/dt étudiés.

- application à partir d'un seuil d'accélération de +2 Gz, sans tenir compte de l'effet lié à G qui apparaît relativement peu important.

Hors du domaine de l'étude (d(G)/dt > 1G/s) il est difficile d'évaluer l'évolution que devrait suivre ce bruit. Une extrapolation prudente peut, sans trop de risques, être effectuée jusqu'à 2 G/s.

Tout laisse cependant penser que l'amplitude des réponses de la tête augmente d'une manière très importante avec la fréquence de la perturbation d'entrée.

Dans ces conditions, la solution la plus simple pour les mesures réalisées avec des d(G)/dt élevés pourraient être d'affecter systématiquement une condition d'impossibilité.

Ces considérations doivent être tempérées par des facteurs liés à la simulation réalisée. En effet, l'addition d'un bruit sur le signal provenant du viseur de casque constitue un élément extérieur au pilote, non corrélé avec ses propres impressions. De plus, il ne faut pas négliger les bruits résultant des conditions de simulation elles mêmes, qui rendent la visée plus imprécise qu'en réalité. Ce sont, par exemple, les petites erreurs résultant d'une correction de parallaxe imparfaite ou les retards dynamiques introduits par le système de calcul. Ces petits défauts de simulation n'existent en principe pas en situation réelle. Ces différents facteurs devraient donc aussi contribuer à la modélisation d'un signal d'erreur destiné à prendre en compte l'effet des accélérations.

5. CONCLUSION

La stabilité de la visée effectuée au moyen d'un viseur de casque se révèle très significativement affectée par les variations d'accélération + Gz. En site, l'écart quadratique moyen sur 8 sujets atteint 0,8° dès 0,3 $G.s^{-1}$ et dépasse 2 degrés à 1 $G.s^{-1}$. L'identification des perturbations de visée dans le domaine fréquentiel s'est avérée difficile, en raison des conditions expérimentales et des variations interindividuelles.

Sur le plan pratique, on peut supposer que le réalisme des études menées en simulateur de combat pourrait être amélioré en surajoutant un bruit (fonction de G et d(G)/dt) aux mesures viseur.

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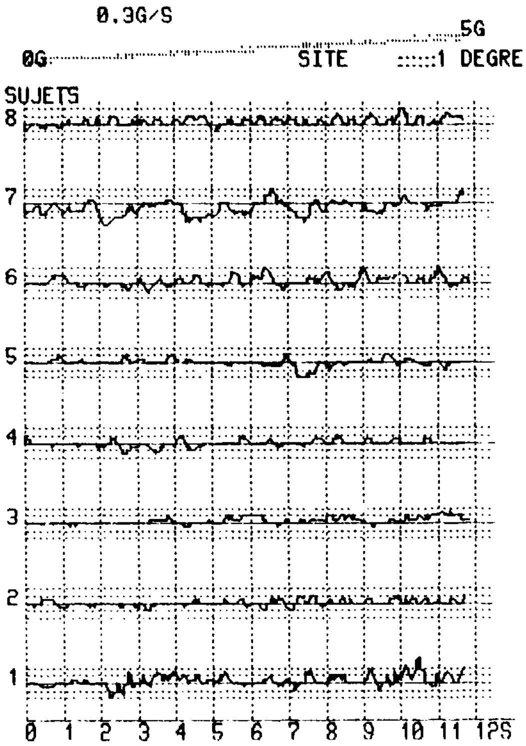

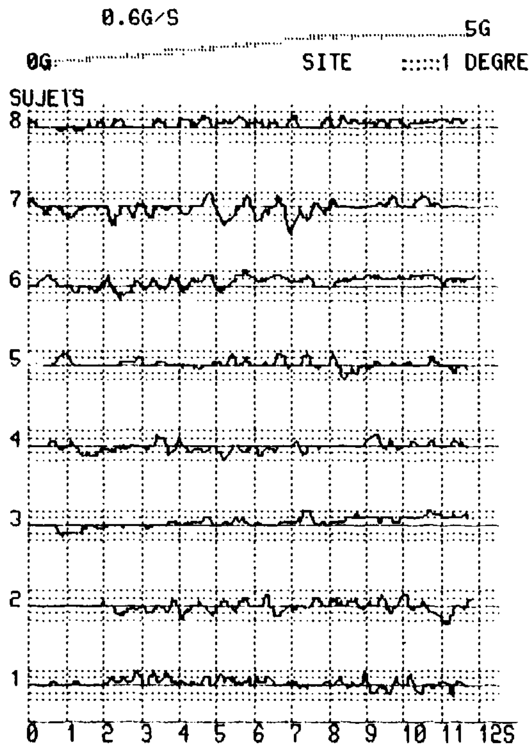

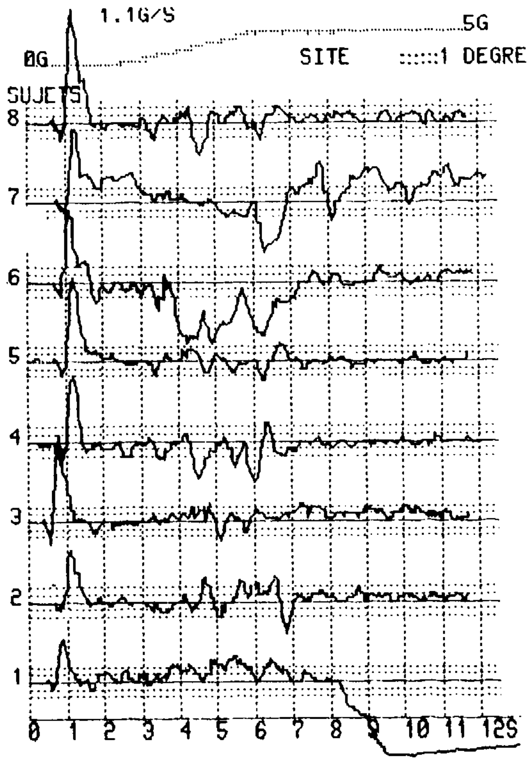

Figures 1, 2, 3 :

Mouvements angulaires en site de la tête autour de la ligne de visée de référence pour des pentes d'accélération de 0,3 - 0,6 et 1 G/s.

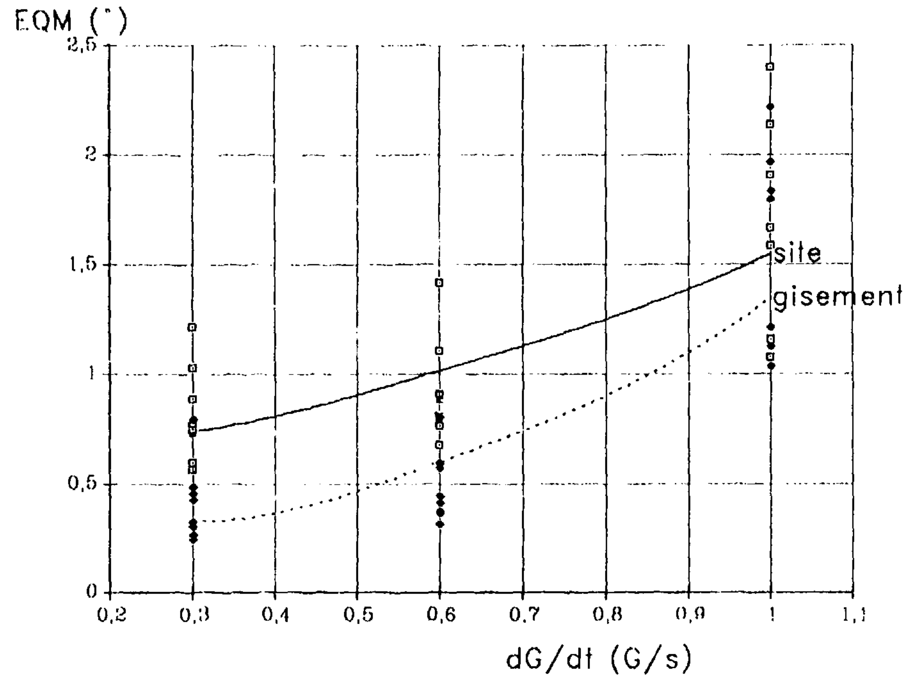

Figure 4 :

Ecarts quadratiques moyens obtenus en site et en gisement pour une visée sur le point de référence site et gisement nuls.

Les valeurs obtenues par les huit sujets ont été présentées, à l'exception des résultats obtenus à 1 G/s par le sujet n° 7.

La courbe de regression des données de site et de gisement obtenue par fonction exponentielle, est également présentée.

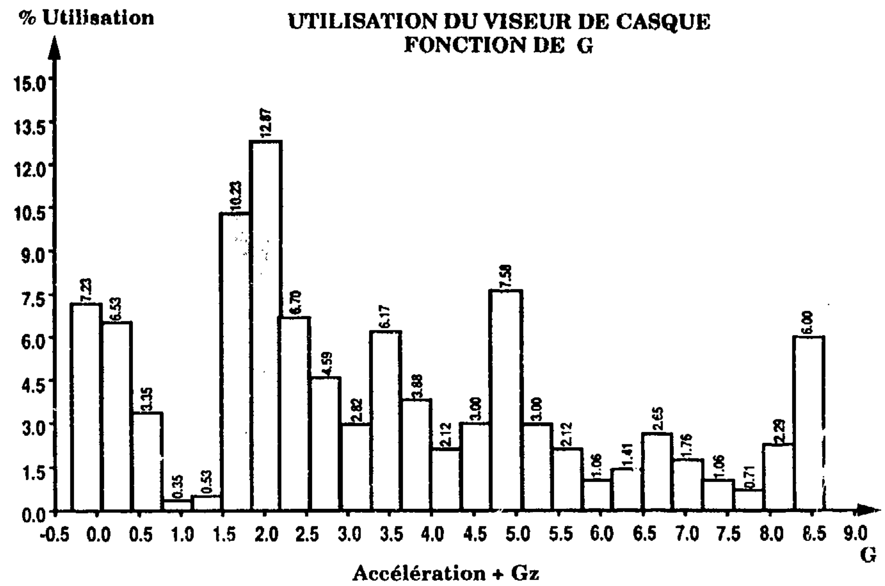

Figure 5 :

Pourcentage d'utilisation du viseur de casque en fonction des niveaux d'accélération. Ces données sont issues de 8 vols effectués en simulateur de combat au CELAR.

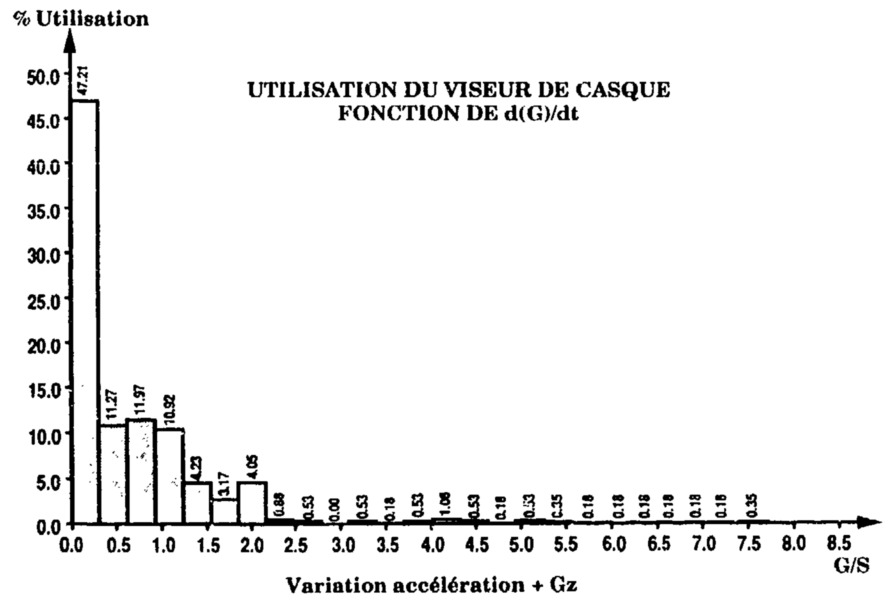

Figure 6 :

Pourcentage d'utilisation du viseur de casque en fonction des variations d'accélération. Ces données sont issues de 8 vols effectués en simulateur de combat au CELAR.

A KINEMATIC MODEL FOR PREDICTING THE EFFECTS OF HELMET MOUNTED SYSTEMS[1]

Terry A. Watkins, Ph.D.
Department of Mathematics, University of New Orleans
New Orleans, Louisiana 70148-0001
USA

M.S. Weiss, Ph.D, Capt. D.W. Call, Ph.D., and S.J. Guccione, Jr., Ph.D.
Naval Biodynamics Laboratory
P.O. Box 29407
New Orleans, Louisiana 70189-0407
USA

SUMMARY

A statistical study was made using head kinematic response data from a set of 79 human -X impact acceleration tests conducted at the Naval Biodynamics Laboratory. Five volunteer[2] subjects were tested successively in three configurations: (a) no helmet, (b) helmet only, and (c) helmet with weights. The peak acceleration levels ranged from 3g to 10g. Three kinematic responses, the X and Z components of the linear acceleration and the Y axis angular acceleration, were analyzed. These acceleration curves were fitted with polynomial splines using least squares techniques. The fitted peaks and times to peak were then regressed against sled acceleration, initial head orientation and head/neck anthropometric parameters. Statistical measures of goodness of fit were highly significant. The regression equations were used to simulate the effects of varying individual parameters (such as total head mass, peak sled acceleration, neck length, etc.).

The results demonstrate an analytical approach for extrapolating human head/neck kinematics to levels and types of exposure where injury would be expected. Future applications of this modeling technique include analysis of the effects of mass distribution parameters on head/neck dynamic response to +Z vertical impact acceleration.

LIST OF SYMBOLS

AAX	X-component of head linear acceleration in the sled coordinate system (m/sec^2)
AAZ	Z-component of head linear acceleration in the sled coordinate system (m/sec^2)
DOP	duration of peak sled acceleration (msec)
ESV	endstroke sled velocity (m/sec)
HM	total head mass. Includes head, mouth instrumentation, and helmet configuration mass (kg)
HO	helmet only configuration
HW	helmet with weights configuration
IDAX	initial X-component of head linear displacement in the sled coordinate system (m)
IDAZ	initial Z-component of head linear displacement in the sled coordinate system (m)
INT	intercept of a regression line
IPHB	initial head angular displacement about Y-axis of head anatomical coordinate system (rad)
NC	neck circumference (cm)
NL	neck length (cm)
NH	no helmet configuration
PSA	peak sled acceleration (m/sec^2)
QHB	head angular acceleration about Y-axis of head anatomical coordinate system (rad/sec^2)
ROO	rate of sled acceleration onset (m/sec^3)

INTRODUCTION

Current aviator helmet developments, which incorporate a variety of helmet mounted protective and weapons related systems including night vision goggles, may compromise aircrew safety. As part of a long-term program to develop criteria for protecting aircrew from the potentially harmful effects of impact acceleration, the Naval Biodynamics Laboratory (NAVBIODYNLAB) is studying human head and neck response to whole-body acceleration to develop predictive models for neck injury.

The regression model reported here can be used to simulate the effects of changes in acceleration profile, mass distribution properties of the head, and varying neck morphology on human head/neck kinematics. Such models allow study of the individual effects of varying parameters (such as head mass) whose experimental measurement might compromise the safety of the volunteers and would require excessive amounts of data. In particular, this paper describes a predictive regression model for unhelmeted and helmeted human head kinematics for the -X vector direction.

METHODOLOGY

(1) Database. The data used in this analysis were obtained from 79 -Gx impact acceleration experiments involving five human research volunteers (HRVs) [Table 1].

Table 1. Test Matrix of Peak Sled Acceleration by Helmet Configuration

Conditions	Subject ID				
	H166	H168	H169	H172	H175
NH 3g	1	1	2	1	1
HO 3g	1	1	1	1	1
HW 3g	1	1	1	1	1
NH 5g	1	1	1	1	1
HO 5g	1	1	1	1	1
HW 5g	1	1	1	1	1
NH 7g	1	1	1	1	1
HO 7g	1	1	1	-	1
HW 7g	-	1	1	-	1
NH 8g	1	2	1	1	1
HO 8g	1	2	2	-	1
HW 8g	-	2	2	-	-
NH 9g	1	1	1	1	1
HO 9g	1	1	1	-	1
HW 9g	-	-	-	-	-
NH 10g	3	3	2	1	3

Number of runs at each configuration and g-level.

[1] The interpretations and opinions in this work are the authors' and do not necessarily reflect the policy and views of the Navy or other government agencies.

[2] Volunteer subjects were recruited, evaluated, and employed in accordance with procedures specified in the Department of Defense Directive 3216.2 and Secretary of the Navy Instruction 3900.39 series. These instructions meet or exceed prevailing national and international standards for the protection of human subjects.

All experiments were conducted at the NAVBIODYNLAB. The experimental and instrumentation details have been extensively reported elsewhere [1-5]. The HRVs were instrumented to measure head and neck displacement and linear and angular acceleration. They were seated with full torso restraint and the head and neck were allowed to move freely. Each volunteer was tested successively in three configurations: (a) no mass addition; (b) helmet and weight-carrier; (c) helmet, weight-carrier, and two pairs of .213 kg weights mounted symmetrically, mid-sagittally high in front. A progression of increasing sled accelerations from 3g to 10g was completed for each configuration.

Figure 1 illustrates typical acceleration time traces for 5g to 10g. The identified parameters include peak sled acceleration (PSA), endstroke sled velocity (ESV), rate of acceleration onset (ROO), and duration of peak acceleration (DOP) [**Table 2**].

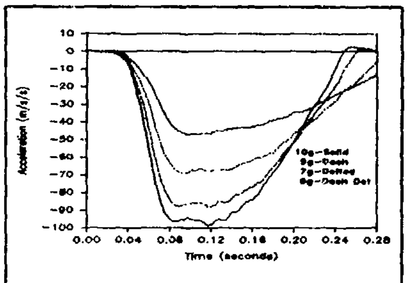

Figure 1. Typical sled acceleration profiles.

Table 2. Range of Sled Acceleration Parameters

Variable	Units	Range
PSA	m/sec^2	28.9 - 98.7
ESV	m/sec	5.5 - 13.8
ROO	m/sec^3	519 - 2679
DOP	msec	128 - 104.2

The selected initial position parameters are the initial head linear displacements IDAX and IDAZ and the initial head angular displacement IPHB [**Table 3**]. These positions are measured with respect to the origin of the sled coordinate system. All tests were run in the nominal neck-up, chin-up (NUCU) condition with IPHB expected to be close to zero radians. Within-subject ranges for the position parameters were much narrower than the overall range of variation.

Table 3. Range of Initial Head Linear and Angular Displacements

Variable	Units	Range
IDAX	meters	-1.332 - -1.243
IDAZ	meters	1.503 - 1.567
IPHB	radians	-.349 - -.025

The identified head/neck anthropometry parameters are head mass, neck length, and neck circumference. Head length and circumference are measured as indicated in **Figures 2 and 3**. Neck circumference is measured as in **Figure 4**. However, neck length is computed as the difference between (T1-top of head) and head height as indicated in **Figures 5 and 6**.

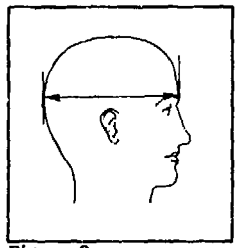

Figure 2.

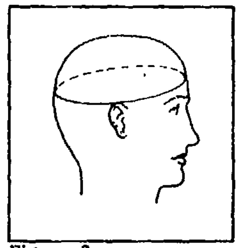

Figure 3.

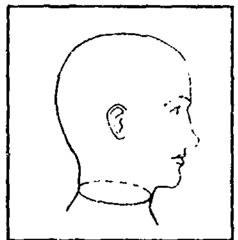

Figure 4.

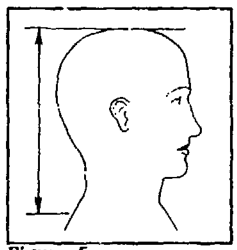

Figure 5.

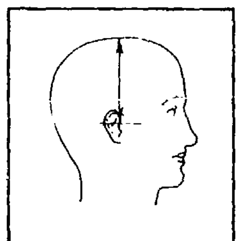

Figure 6.

Head mass for the un-instrumented HRVs were estimated using the formula [6]:

$$HM = .21618\ HC - .12184\ HL - 5.5936$$

where:
- HM = head mass (kg)
- HC = head circumference (cm)
- HL = head length (cm)

The measurements for each HRV are listed in Table 4.

Table 4. Selected Head and Neck Anthropometric Data on Five Volunteer Subjects

Subject	Head Length (cm)	Head Circum. (cm)	Head Mass (kg)
H166	20.1	56.5	4.172
H168	21.1	58.9	4.569
H169	19.5	57.0	4.353
H172	19.6	57.8	4.513
H175	19.5	56.6	4.266

Subject	T-1/Top of Head (cm)	Head Height (cm)	Neck Length (cm)	Neck Circum. (cm)
H166	27.3	13.4	13.4	36.3
H168	26.4	13.9	12.5	39.0
H169	26.7	13.2	12.5	38.0
H172	27.9	12.8	15.1	36.9
H175	27.3	12.4	14.9	37.2

The added head mass for each subject for each configuration is shown in Table 5. The added mass in the unhelmeted case consists of the mouth mount, T-plate and connecting straps. The shifts in the X and Z components of the center-of-gravity (c.g.) are with respect to the c.g. taken from cadaver data [11]. The shift in the Y component of the c.g. is negligible, due to the lateral symmetry of the total head mass.

Table 5. Added Head Mass and Shift in c.g. for Each Subject for Each Configuration

Subject	HU (kg)	c.g. shift (cm)	HO (kg)	c.g. shift (cm)	HV (kg)	c.g. shift (cm)
H166	0.493	1.0, -0.8	0.983	1.0, -0.1	1.835	1.9, 1.0
H168	0.477	1.0, -0.8	0.996	1.0, -0.1	1.848	2.0, 1.0
H169	0.474	1.0, -0.7	0.985	1.0, 0.1	1.837	1.9, 1.1
H172	0.486	1.0, -0.8	1.021	1.0, -0.1	1.873	2.1, 0.7
H175	0.482	1.1, -0.7	0.893	1.2, -0.2	1.745	2.3, 0.7

(2) Analysis. To smooth the data, the head linear and angular acceleration curves (AAX, AAZ, and QHB) were fitted with polynomial splines using least squares techniques [7, 8, 9]. For each curve, the times to peak and peak amplitudes for the first five peaks were determined from the fitted curve [Figure 7].

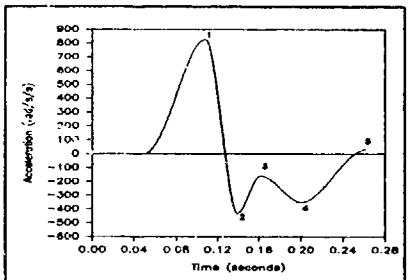

Figure 7. The five chosen peaks for QHB.

These computed values were then regressed against the four sled parameters (PSA, ESV, ROO, DOP), the initial head orientation in the X-Z plane (IDAX, IDAZ, IPHB) and several functions of three anthropometric parameters (head mass, neck length, neck circumference) to obtain a prediction model for peak values for each curve. Several SAS® regression programs (STEPWISE, RSQUARE, REG) were used in the parameter selection process.[3] A simulation model was developed by adding appropriate normally distributed errors to the prediction model. The predicted curves are obtained by fitting the predicted peak values with cubic splines. Estimated upper and lower confidence bands for each curve were generated by simulating the predicted curve 100 times and determining the upper and lower boundaries.

RESULTS

The regression models for the peak values and times to peak for the three kinematic parameters are listed in **Appendix I**. **Figures 8 - 10** illustrate the estimated confidence bands for the three kinematic curves for test LX5460. **Figures 11 - 13** illustrate the effect of varying only the acceleration profile parameters. PSA and ESV were the parameters perturbed in the simulations since they were the sole acceleration profile parameters appearing in the various regression models. As expected, peak magnitudes increase and times to peak decrease with increased PSA and ESV for all three kinematic responses.

Figures 14 - 15 illustrate the effect on AAZ of varying added head mass from 0.0 kg to 3.0 kg at 8g and 16g respectively. **Figures 16 - 17** illustrate the same effect on angular acceleration, QHB. There is no statistically significant effect on AAX due to head mass. These effects are small. The decrease in peak head acceleration is only 7 m/s^2 and 60 rad/s^2 for each additional kg of added mass. The effects of the input acceleration (PSA) are much greater than these small effects as illustrated in **Figures 18 - 21**.

Figure 18 shows that a 1g increase in PSA almost cancels the effect of a 2 kg increase in added mass. These opposing effects are illustrated in **Figure 19** which shows that a .5g increase in PSA cancels the opposing effect of a 1 kg addition to head mass. These effects for head linear acceleration also hold true for angular acceleration [Figures 20 - 21].

Regarding neck anthropometry, peak magnitudes of head acceleration decrease with increasing neck circumference and increasing neck length. Because of the narrow range of neck anthropometry represented by the five subjects, no general conclusions can be drawn. However, these two neck anthropometry parameters do contribute significantly to the predictive model adding from 6 to 10 percent of R^2 in some cases [10].

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[3] SAS Institute, Inc., SAS/STAT®, Release 6.01.

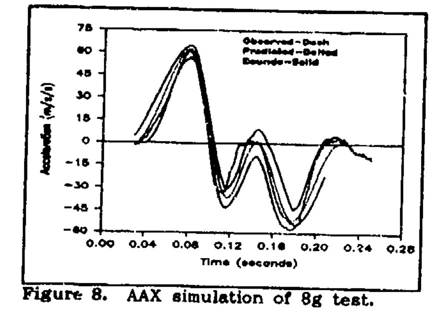

Figure 8. AAX simulation of 8g test.

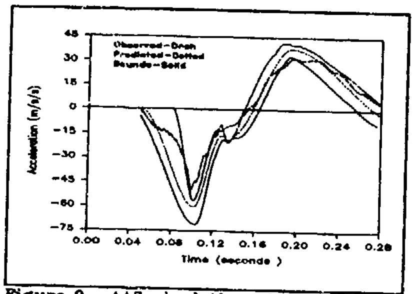

Figure 9. AAZ simulation of 8g test.

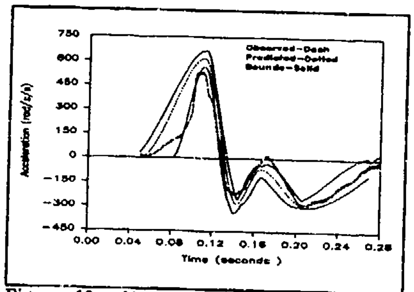

Figure 10. QHB simulation of 8g test.

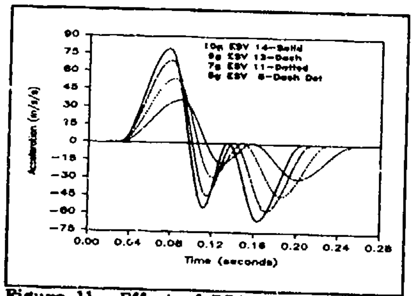

Figure 11. Effect of PSA and ESV on AAX.

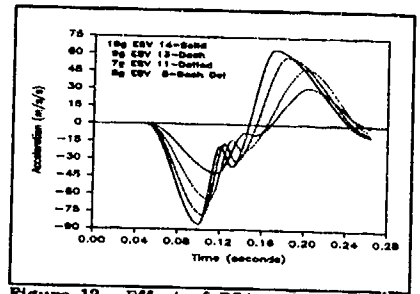

Figure 12. Effect of PSA and ESV on AAZ.

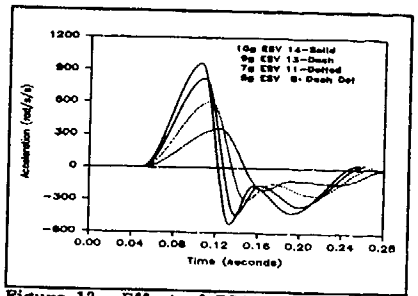

Figure 13. Effect of PSA and ESV on QHB.

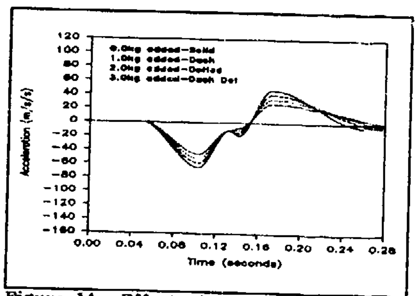

Figure 14. Effect of added mass on AAZ at 8G.

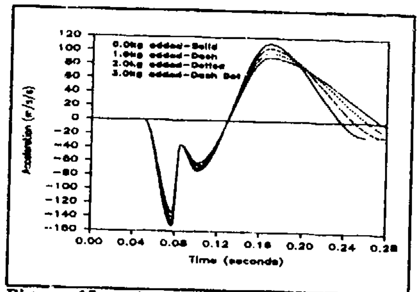

Figure 15. Effect of added mass of AAZ at 16g.

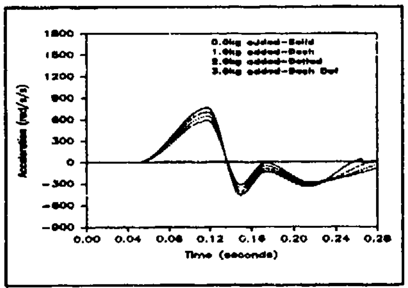

Figure 16. Effect of added mass on QHB at 8g.

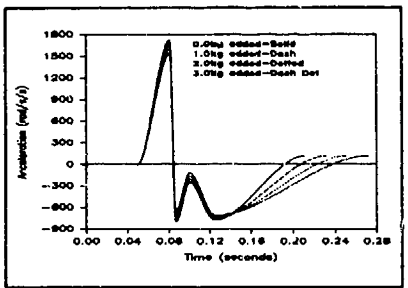

Figure 17. Effect of added mass on QHB at 16g.

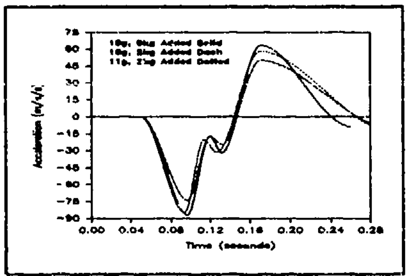

Figure 18. Relative effect of PSA and added head mass on AAZ (10g, 0kg base level).

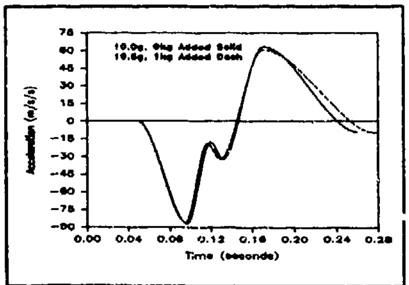

Figure 19. Combinations of PSA and added head mass yielding equivalent AAZ.

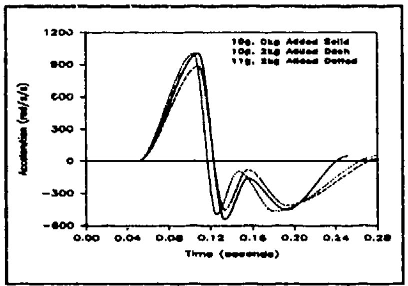

Figure 20. Relative effects of PSA and added head mass on QHB (10g, 0kg base level).

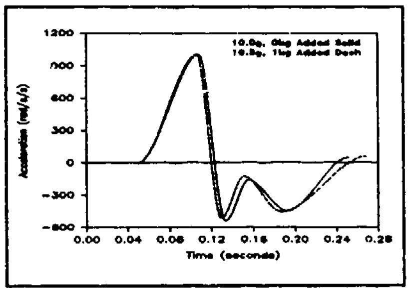

Figure 21. Combinations of PSA and added head mass yielding equivalent QHB

DISCUSSION AND CONCLUSIONS

The results of this study provide an analytical approach to extrapolating helmeted human volunteer head/neck kinematics to levels where injury might be expected. A single analytic model describes both helmeted and unhelmeted kinematics with total head mass being the sole head inertial parameter required. Based on this model, added head mass reduces peak head linear and angular acceleration for -Gx. This reduces the increase in the estimated forces and torques at the occipital condyles [5] due to this added mass. Analysis of these interacting effects requires more detailed models.

Future models will incorporate all the various head inertial parameters (center of gravity, moments, etc.) among the independent regression variables. The influence of neck anthropometry on head kinematics will also be incorporated, using a greater range of data.

The basis for this model development is the +Z vertical helmeted test series presently underway at NAVBIODYNLAB. Twelve subjects are being tested under nine different mass addition treatments at levels ranging from 3 to 8g's. The range of acceleration profile, head mass distribution, and neck anthropometry parameters covered by this series will yield a definitive regression model for human +Z helmeted head kinematics. This model can be used to analytically validate anthropomorphic manikins, to check biomechanical models of human response to +Z impact acceleration with various helmet mounted devices, and to help establish tolerance limits for inertial loading due to such systems.

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APPENDIX I: Regression Tables

AAX TABLE

	INT	PSA	ESV	NC	NL	NL^2	NL^3
P1	21424	.87		-262	-465951	3384003	-8169785
P2		-1.54	7.04				
P3	-176			466			
P4	-27563	-.71			612667	-4523065	11092403
P5	-.70						

	INT	PSA	ESV	NC	NL	NL^2	NL^3
T1	5.38		-.0020	-.1348	-114	820	-1969
T2	.15		-.0031				2
T3	.08	-.0004		.2671			
T4		-.0007		.5852			6
T5	.45		-.0091	.5638		-58	294

AAZ TABLE

	INT	ESV	IDAX	IPHB	HM	NC	NL	NL^2
P1	-156	-8			6	401		
P2		-2	-66	39		-172		
P3	-1450	-5	108	39	4		23647	-86626
P4		6	-117		-7		-1986	7162
P5	11	-1						

	INT	PSA	ESV	IDAX	IPHB	HM	NL
T1		-.0003		-.0996	-.0245		
T2	.1789		-.0042				
T3	.1825		-.0037				
T4	.1309	-.002	.0206				.3387
T5						.0185	1.3635

QHB TABLE

	INT	PSA	ESV	IDAX	IDAZ	IPHB	HM	NC	NL	NL^2	NL^3
P1	590152	12			-3383		-59	4481	-12776351	93057989	-225326898
P2	-3282	-14	66		1945		46				
P3	-2514		-10	-427	1182	180	41				
P4	1220	-5		984		-178	20				
P5	-1828		8		1176	191					

	INT	ESV	IDAX	IDAZ	HM	NC	NL^3
T1	.3268	-.0033	-.0999	-.1949			
T2	.2034	-.0056					[illegible]
T3	.2457	-.0065					
T4		-.0081				.6825	18
T5	.1946	-.0049			.0201		18

The Effects Upon Visual Performance of Varying Binocular Overlap

G. K. Edgar, K.T. Carr, M. Williams, J. Page and A.L. Clarke.

Human Factors Dept., Sowerby Research Centre, British Aerospace PLC,
FPC 267, PO Box 5, Filton, Bristol, BS12 7QW, England.

Summary.

In a helmet mounted display there is a trade-off between the binocular overlap of the images presented to each eye and the total field of view. It is therefore desirable to see whether decreasing the binocular overlap (and thus making possible a larger total FOV) adversely affects performance. This paper reports the results of four experiments examining the effects of different binocular overlaps upon performance on a visual search task, and the factors that may explain any differences in the results obtained with different overlap conditions. The results indicated that performance was poorer in all non-100% overlap conditions, and suggested that this decrement in performance could be explained by the presence of depth boundaries introduced by a disparity between the images presented to each eye.

Introduction.

The optimum field-of-view (FOV) for a binocular HMD will be, to a certain extent, task dependent. For some tasks, such as visual search, a wide FOV is likely to improve performance. Currently however, the optical components needed to provide a wide binocular FOV would be too large and heavy for practical applications in the military cockpit. However, it may be possible to increase the total FOV without increasing the bulk of the optical components by reducing the binocular overlap from 100% to a level which, while giving an increased FOV, does not significantly detract from the pilot's performance on visual tasks. The trade-off between FOV and binocular overlap is illustrated in Figure 1.

A number of studies have examined the effects of different degrees of binocular overlap on visual performance. Kruk and Longbridge [1] found evidence of a degradation in the detection of motion at the edges of a 25 deg overlap field. A study by Melzer and Moffitt [2] suggested that the binocular overlap should be at least 50%, providing this gives an angular overlap of at least 20 deg. Landau [3] measured performance on a visual recognition task to assess the effects of binocular overlaps ranging from 17 to 47 deg. They found that performance was markedly worse for a small binocular overlap.

The experiments reported in this paper examine performance on a visual search task with different degrees of binocular overlap, and examine possible explanations for the differences in performance that were found in different conditions.

Experiment 1.

The effects of display binocular overlap on visual search times: overlap varied by adjusting eyepieces and image.

Methods.

A visual search task was used in which the subjects were asked to locate a V in an array of Xs. This task was chosen as the visual task as it is a relatively simple task, and requires visual processing over the whole search field. An example of the search field is presented in Figure 2. The search field was presented binocularly with varying amounts of overlap between the images presented to each eye. The images to be presented to each eye were displayed on Barco "Calibrator" monitors. The luminance of the light portions of the display was 40 cd m^{-2} and the luminance of the dark regions was 3 cd m^{-2}. Apparent viewing distance was 0.6m. Subjects viewed the images dichopti-

cally via a lens and fibre-optic system. In this experiment, the degree of overlap was altered by changing both the angle of the eyepieces and the position of the imagery. Thus, with different overlaps, the available FOV also changed (although any extra FOV was not used).This condition therefore mimics potential HMD optical arrangements. The size of the search field remained constant across all conditions. The method of changing the overlap is illustrated in Figure 3. Before each condition, subjects were presented with a calibration display consisting of coloured vertical lines. The subjects were instructed to adjust the eyepieces until the images presented to the two eyes were fused and only one set of lines was visible. The lines were moved over the display for different conditions, requiring the subjects to diverge the eyepieces by different amounts to allow the fusion of the images. The angle of the eyepieces was only changed in this first experiment; in the following three experiments the eyepieces were set up at the start of the experiment and then remained in the same position for all conditions (as described in the Methods for Experiment 2). All subjects were tested for, and found to have, normal stereo vision.

Four conditions were tested and these were as follows:

Overlap (appx.)	Search field	FOV
0%	15.5 deg	70 deg
17%	15.5 deg	67 deg
50%	15.5 deg	62 deg
100%	15.5 deg	35 deg

The different conditions were presented in a balanced order to control for possible order effects. There were twenty trials in each run. Subjects were instructed to look for a V positioned randomly in the array and to press a button as soon as the V was located. As soon as the subject had responded the screen was cleared and the subject then had to report in which quadrant the V had appeared. This allowed a check of the response accuracy of the subjects. In all the experiments reported in this paper there were almost no errors in the report of which quadrant the V was located. Any errors that occurred were usually due to the fact that the V was located very close to a boundary between two quadrants, and the subject had presumably misjudged where the boundary was. The time taken to locate the V, and the quadrant in which the subject reported the V to be, were recorded. Eight subjects were tested once(20 trials) in each condition.

Results.

The median search times for all four conditions are shown in Figure 4. A log transformation, followed by an analysis of variance, was applied to the data. The analysis revealed a significant ($p < 0.05$) difference between the 100% overlap condition and all non-100% overlap conditions. There were no significant differences between the other conditions.

All subjects were able to fuse the two images in all conditions. There were no reports of diplopia.

Discussion.

The results suggest that there is a significant advantage in having 100% overlap for a visual search task. However, the method of varying the overlap in this experiment meant that, in all non-100% overlap conditions, the subjects were looking through the eyepieces off-axis. This may have resulted in a certain amount of distortion of the image, which may have affected the results independently of the effect of binocular overlap. Image quality is obviously an important consideration in the design of any HMD. Unfortunately, with the eyepeices used in these experiments there was a certain amount of distortion around the edges, which, as mentioned above, may have had an effect on performance. However, all the follow-

ing experiments were designed so that any distortion of the image would affect all conditions equally. The next experiment was designed to address the possibility that the poorer performance in the non-100% overlap conditions was due to differences in the optical set-up between conditions.

Experiment 2.

The effects of display binocular overlap on visual search times: overlap varied by adjusting image only.

Although the results of Experiment 1 suggested that performance on a visual search task was poorer for all non-100% overlap conditions, this may have resulted from the change in the optical configuration used to adjust the binocular overlap. Therefore, in this experiment, the overlap was changed by adjusting only the image; the optical set-up remained the same in all conditions.

Methods.

The methods used were almost identical to those used in experiment 1. The only difference was that the binocular overlap was varied by changing the position of the image only (as illustrated in Figure 5). Thus, the optical arrangement and the total FOV was the same in all conditions. The effects of the same four binocular overlaps used in Experiment 1 were investigated. Thus the four conditions tested were:

Overlap (appx.)	Search field	FOV
0%	15.5 deg	35 deg
17%	15.5 deg	35 deg
50%	15.5 deg	35 deg
100%	15.5 deg	35 deg

All other details of the method were the same as those in Experiment 1.

Results.

The median search times for all four conditions are shown in Figure 6. A log transformation, followed by an analysis of variance, was applied to the data. The analysis revealed a significant ($p < 0.05$) difference between the 100% overlap condition and all non-100% overlap conditions. The only other significant difference was between the 0% and 17% overlap conditions.

All subjects were able to fuse the two images in all conditions. There were no reports of diplopia.

Discussion.

The results of this experiment suggest that the poorer performance in the non-100% overlap conditions found in Experiment 1 were not due to the changes in the optical arrangement.

Thus the results of Experiments 1 and 2 suggest either that having a 100% overlap is inherently better, or that there are factors associated with non-100% overlap that adversely affect performance. The effect at this stage appears to be an all-or-nothing effect, as performance in all three non-100% conditions was degraded. However, performance in the 17% overlap condition was degraded to a lesser extent than performance in the other non-100% overlap conditions (although still significantly worse than 100% overlap). The reason for this difference is unclear. A number of subjects commented on the salience of the boundaries between the overlapping and non-overlapping regions of the display. It is possible that the two narrowly spaced boundaries in the 17% overlap condition might be less disruptive than the more widely spaced boundaries in the 50% overlap condition.

There appear to be two main reasons why the subjects might be aware of the boundaries between the overlapping and non-overlapping regions. Some subjects noticed that the overlapping portion of the display appeared to be slightly brighter than the non-overlapping portion. Also, many subjects reported that the overlapping portion of the display

often appeared to be at a slightly different depth to the non-overlapping portion.

The following two experiments were designed to see whether or not these factors might account for the poorer performance of subjects on the visual search task when the display was overlapped by less than 100%.

Experiment 3.

Brightness matching of overlapping and non-overlapping portions of the display.

This experiment was designed to see whether the perceived mismatch in brightness between the different regions of the display affected performance in the non-100% overlap conditions. Subjects were thus able to adjust the brightness of the overlapping portion of the display until no brightness difference was evident.

Methods.

The search task and methods were identical to those described in Experiment 2, apart from the matching of the brightness of the overlapping region of the display. Three conditions were tested. These were:

a) 100% overlap.

b) 50% overlap - no brightness matching.

c) 50% overlap - brightness matching.

Conditions **a** and **b** were identical to those in Experiment 2. In condition **c**, before beginning the search task, subjects were asked to adjust (using a method-of-adjustment procedure) the brightness of the overlapping portion of the display until there appeared to be no difference in brightness between the overlapping and non-overlapping regions. The luminance of the match made by each of the subjects was recorded as this gave an indication as to whether or not there was actually a difference in the perceived brightness of the overlapping part of the display that could be eliminated by adjusting the luminance of this portion

Four subjects were tested, and each subject repeated the three conditions four times (20 trials in each condition). The different conditions were presented in a balanced order to control for possible order effects.

Results.

The mean brightness matches made by all four subjects are shown in Figure 7. None of the brightness matches made by any of the subjects was significantly different to the (unchanged) brightness of the rest of the display. The median times taken to locate the target V in each of the three conditions are shown in Figure 8. A log transformation, followed by an analysis of variance, was applied to the data. The analysis revealed a significant ($p < 0.05$) difference between the results of condition **a** and conditions **b** and **c**, but no significant difference between conditions **b** and **c**. That is, performance was similar in each of the two 50% overlap conditions but performance in both these conditions was poorer than that in the 100% overlap condition.

All subjects were able to fuse the two images in all conditions. There were no reports of diplopia.

Discussion.

The variability of the brightness matches and the fact that none of the matches was significantly different from the original value suggests that a brightness difference is unlikely to be responsible for the subjects poorer performance in the non-100% overlap conditions. The subject's performance on the visual search task also suggests that a perceived brightness difference is not affecting performance; performance in the matched brightness condition was no better than that in the unmatched condition and worse than that in the 100%

overlap condition. It is possible that the observed differences between the overlapping and non overlapping regions of the display (i.e. perceived differences in brightness and depth) may both have arisen as a result of a disparity between the two images. A disparity between the two images may give an impression of depth and some studies[4,5,6] have suggested that a difference in the perceived depth of two surfaces may also lead to a difference in perceived lightness. It should be stressed that lightness (the apparent reflectance of a surface: independent of ambient illumination) is distinct from brightness (the amount of light perceived to be coming from a surface: dependent upon both reflectance and ambient illumination). It is possible, therefore that, as a result of a perceived depth difference between parts of the display, the subjects were reporting a difference in perceived *lightness* and not brightness. If this was the case, then it is perhaps hardly surprising that in Experiment 3 the attempts to match the brightness of the different regions had no obvious effect on performance.

The next experiment thus investigates the second factor that may have caused the poorer performance in the non-100% overlap conditions; the difference in perceived depth between the overlapping and non-overlapping regions reported by some subjects.

Experiment 4.

The effect of introducing depth boundaries into a 100% overlap display.

Differences in perceived depth between the overlapping and non-overlapping regions of the display can arise as a result of a slight disparity between the two images. This depth difference is particularly evident at the boundaries of the two regions, and it is these 'depth boundaries' that a number of subjects commented on. If these boundaries could be eliminated from the non-100% overlap conditions by eliminating any possible disparity between the two images, it would be possible to see whether the poorer performance in these conditions is due to the presence of these depth differences. Unfortunately, it is virtually impossible to be certain that there is no disparity between the two images. Even if the apparatus could be set up and calibrated in the laboratory in such a way that all disparity between the two images was eliminated, it is quite possible that in a production HMD such fine adjustments would not be possible. Also, it is possible that the two images in a HMD might become slightly misaligned during use. Finally, even if the images within a HMD could be aligned perfectly, there is always the possibility of a change in the vergence angle of the eyes of the pilot using the display. This, in itself, would introduce a disparity between the images. There is a considerable amount of evidence to suggest that, in the presence of reduced stimulation (in bright, low contrast, fields or in darkness), vergence and accommodation tend to lapse towards an intermediate resting state[7,8,9,10,11]. It has also been suggested that stress can affect vergence[11].

Thus, given the difficulty of eliminating all disparities (and the resultant depth boundaries) from the display it is desirable to try and ascertain just what the effect of these disparities (independent of binocular overlap) might be. Therefore, in the following experiment, rather than attempting to eliminate the depth boundaries in the non-100% overlap condition and seeing if performance improved, boundaries were introduced into the 100% overlap condition (by introducing a known disparity) to see if performance worsened.

Methods.

The experiment was set up as for the 100% overlap condition in experiment 2, except that the middle portion of the image presented to one eye was shifted sideways (as illustrated in Figure 9). This introduced a binocular disparity into the centre portion of the display when presented dichoptically, giving it the appearance of being at a slightly different depth to the surround regions. Thus, this mimicked in the 100% over-

lap condition, the effect of the depth boundaries which may have been present in the non-100% overlap conditions. The size of the region shifted sideways was such that the depth boundaries would be expected to occur in the same place as those observed in the 50%-overlap condition, to allow comparison of the two. It should be noted that, in this experiment, although there may also have been some disparity between the two images as a result of (for example) misalignment of the optics (or vergence changes) this will appear as a displacement in depth of the whole search field; boundaries *within* the search field will only arise as a result of the disparity deliberately introduced into one of the images. Thus it was possible to study the effects of depth boundaries introduced as the result of a known disparity.

The effects of three different disparities were tested. These disparities were:

a) 0.093 deg.

b) 0.'86 deg.

c) 0.279 deg.

Four subjects were tested. These were the same four subjects that took part in Experiment 3. Each subject repeated each of the conditions three times. There were 20 trials in each run. The subjects were also tested at zero disparity to ensure that their results in this condition were similar to those obtained in the 100% overlap condition tested in Experiment 3. The different conditions were presented in a balanced order to control for possible order effects.

Results.

The results for all four subjects are shown in Figure 10. A log transformation, followed by an analysis of variance, was applied to the data. The analysis revealed a significant difference ($p < 0.05$) in performance between the zero disparity condition and the two larger disparity conditions (0.186 deg. and 0.279 deg.). There was no significant difference between the 50%-overlap condition (data from Experiment 3) and any of the non-zero-disparity conditions.

All subjects were able to fuse the two images in all conditions. There were no reports of diplopia.

Discussion.

The results of Experiment 4 show a clear effect of introducing a disparity into one portion of one image of a binocular display. The magnitude of the resulting decrement in performance is sufficient to account for the difference in performance between the 100% and non-100% overlap conditions found in previous experiments. It is possible, however, that other factors may also play a part. These results merely suggest that the effects of a disparity between two images *could* account entirely for the difference between the overlapping and non-overlapping conditions - but does not entirely rule out other factors.

General Discussion.

The experiments discussed above examined the effects of different degrees of binocular overlap within the central 15.5 deg of the visual field, and addressed some of the possible causes for the poorer performance of most subjects in the non-100% overlap conditions. The most likely cause of these decrements seems to be the possibility of depth boundaries occurring within the display as a result of a disparity between the two images. Although it is possible that other factors may also contribute to the observed decrements in performance, these studies have demonstrated that introducing a disparity into the two images can adversely affect search performance and furthermore, that introducing a retinal disparity into one region of the display can reduce performance in the 100% overlap condition to a similar level to that observed in the non-100% overlap conditions.

There are two parameters in the experi-

mental design in these experiments that may be different to the set-up in a production HMD. The first is that a relatively small search field (15.5 deg) was used in these experiments. This is almost certainly smaller than the likely FOV for a production HMD. The reason for this small search field is that it allowed the subjects to view the display through the centre of the optics, thus giving minimum distortion of the search field. Also, the effects that were being studied (the effect of brightness and disparity differences) might be expected to be greater within the central visual field, and this is adequately covered by the display used. Presumably the effect of these boundaries would be less evident the further away from the central visual field they occured, but in any task that required a search of the whole field, such boundaries might be expected to impair performance.

The second difference is that the display was presented at an apparent distance of 0.6m. Current head-up displays (HUDs) are infinity collimated, and it seems likely that HMDs may be set up in a similar way (although, given that there are sometimes accomodation problems with HUDs the collimation of HMDs should be carefully considered). The reason for setting the display up in this way is that one of the factors the experiments were designed to investigate was the boundaries that may be introduced by a disparity between the two images. As discussed earlier, one way in which a disparity might be introduced into the image in a HMD would be by a shift in the vergence angle of the eyes of the person using the display. A number of studies have suggested that, even if a display is collimated to infinity there may be a tendency for vergence and accommodation to lapse towards an intermediate value[7,8,9,10,11], particularly in the absence of stimulation (although there is some evidence that accommodation may drift towards a resting level in a prolonged search task[12]). The average resting position is approximately 0.6m. Thus 0.6m was chosen as the viewing distance as it was hoped that this would minimise any changes in accommodation during the experiment. It should be noted, however, that, in Experiment 4 where the disparity between the two images was being investigated, any change in eye vergence, although it may have produced a binocular disparity over the whole display, would not have affected the additional disparity introduced into part of the display - and it is the effect of this disparity that wa s being studied.

Although the search field used in this task was relatively small, it is likely that the presence of depth boundaries could affect search performance in larger displays and with larger degrees of binocular overlap, although perhaps to a lesser degree. Presumably, the effects of depth boundaries introduced by a disparity between the images presented to each eye could explain the poorer performance in all overlap conditions less than 100% but greater than 0%. The 0% condition, however, cannot be explained in this way, and the results of Experiments 1 and 2 suggested that performance in this condition was as bad as that in the other non-100% overlap conditions, and significantly worse than the 100% overlap condition. However, in the 0% overlap condition the boundary between the two halves of the image, although perhaps not arising as a result of a perceived difference in depth, was quite noticeable and there was also a tendency, noted by some subjects, to attempt to fuse points lying on either side of the boundary. Although, the border in this condition may be noticeable for different reasons to those that cause the decrements in the other non-100% overlap conditions, the salience of this boundary might still affect performance. For a HMD, having zero overlap would probably be unwise because, if the boundary is visible at all, it will fall across the centre of the display, where it might be expected to have the greatest effect on performance.

In conclusion, it seems that in a binocular display, such as those proposed for HMDs, any disparity between the two images might lead to a difference in

perceived depth between overlapping and non-overlapping regions of the display. This depth difference may lead, not only to a decrement in performance on a search task, but also to differences in perceived lightness between different portions of the display.

The stimuli used in these experiments were relatively simple and were very effective at revealing some of the problems that have been discussed in this paper. Whether the same problems would be evident with more complex displays, such as those that might be used in production HMDs, remains to be seen. However, the problems discussed above should certainly be addressed in the design of any HMD.

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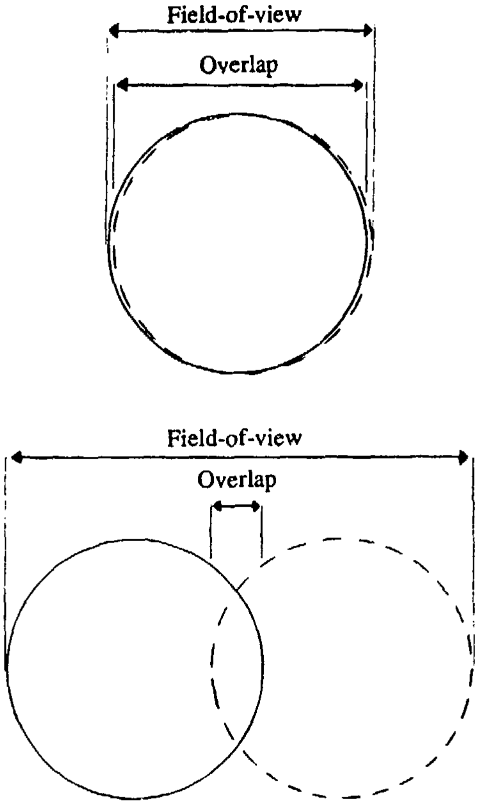

Fig. 1. An illustration of the trade-off between binocular overlap and field-of-view. The broken circle illustrates the view presented to one eye, the solid circle the view presented to the other eye. The upper diagram illustrates the field of view resulting from a large (almost 100%) binocular overlap. The lower diagram illustrates the relatively larger field-of-view that can be obtained by reducing the degree of binocular overlap.

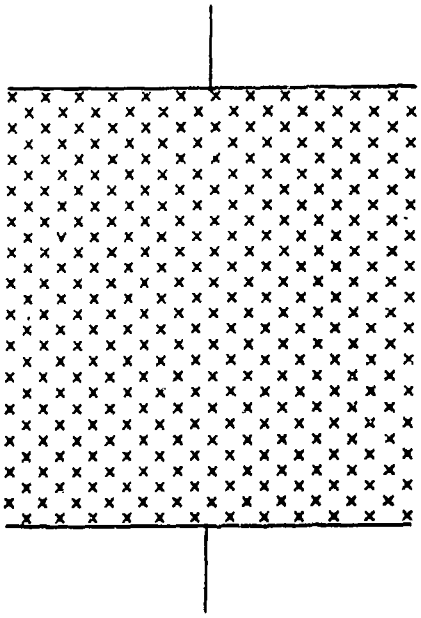

Fig. 2. An example of the search field used in all four experiments. The subjects task was to locate the single V target in an array of this nature.

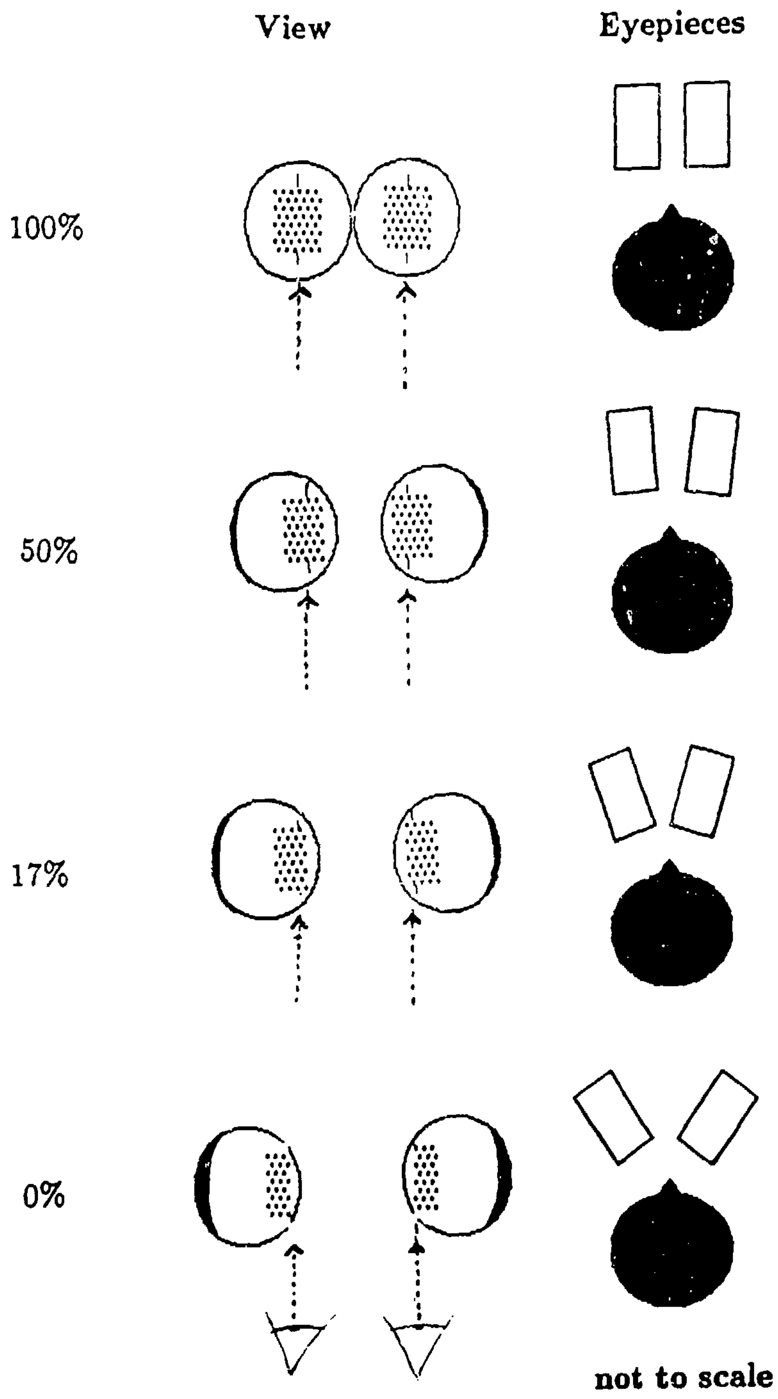

Fig. 3. Method of changing binocular overlap by adjusting the eyepieces.

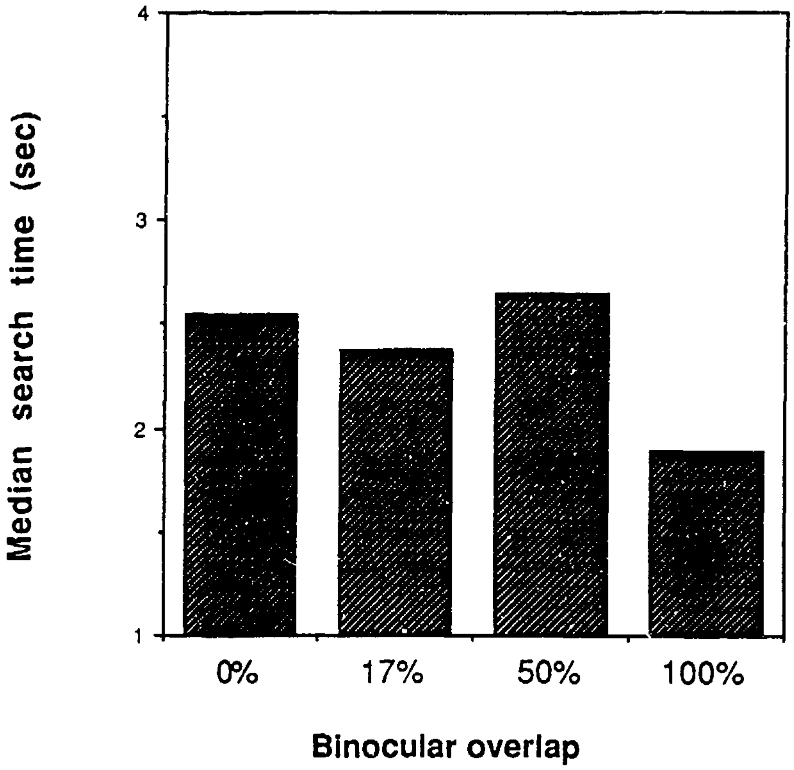

Fig. 4. Median search times (mean of eight subjects) for four different binocular overlaps in Experiment 1.

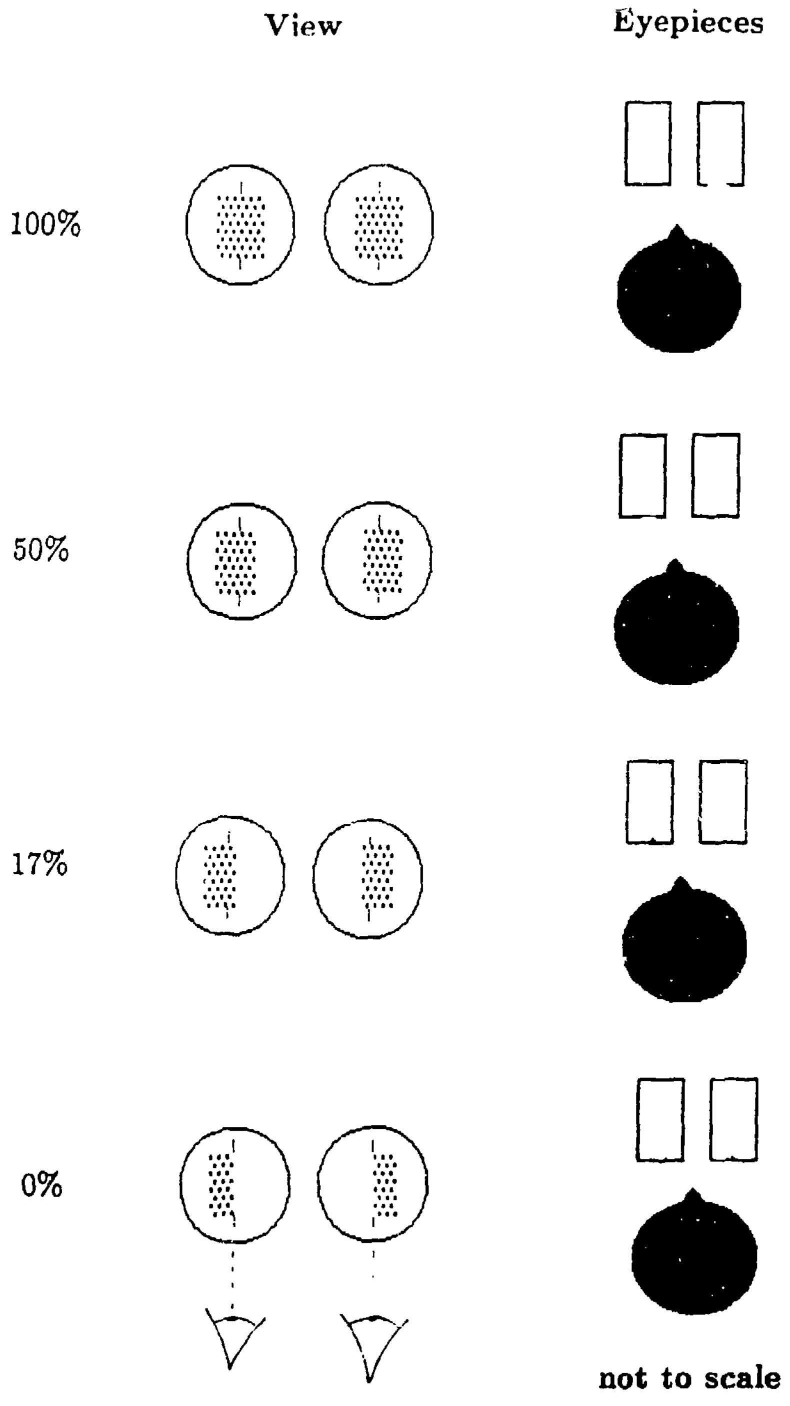

Fig. 5. Method of changing binocular overlap by adjusting only the images. Optical arrangement remained the same in all conditions.

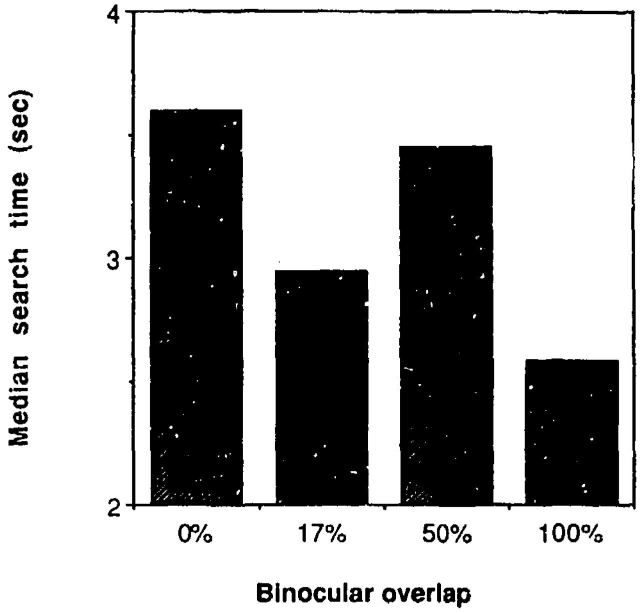

Fig. 6. Median search times (mean of eight subjects) for four different binocular overlaps in Experiment 2.

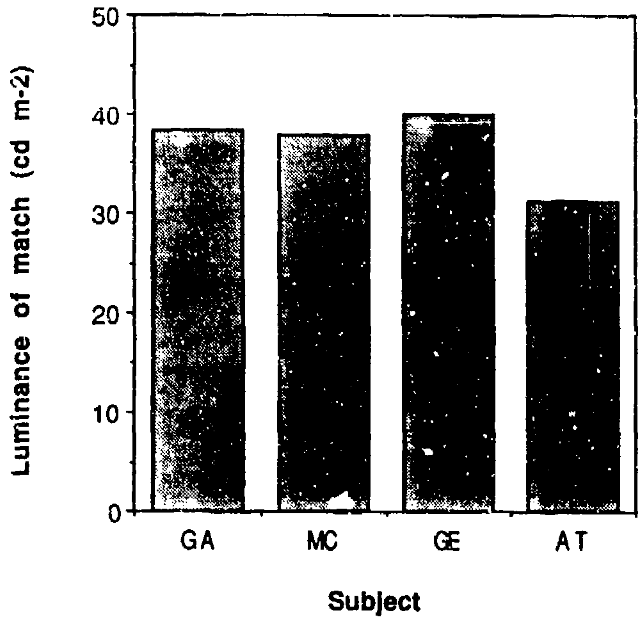

Fig. 7. Mean brightness matches made by all four subjects in Experiment 3. Luminance values are for the matched portion of the image before superimposition. 40 cd m^{-2} was the brightness of the non-overlapped portion of the display. Thus a match value of 40 cd m^{-2} indicates that the subject did not perceive any difference in brightness between the overlapping and non-overlapping portions of the display. Any value less than 40 cd m^{-2} indicates that the subject perceived the overlapped portion of the display as brighter than the non-overlapped; a value greater than 40 cd m^{-2} indicates that the subject perceived the overlapped portion to be dimmer than the non-overlapped portion.

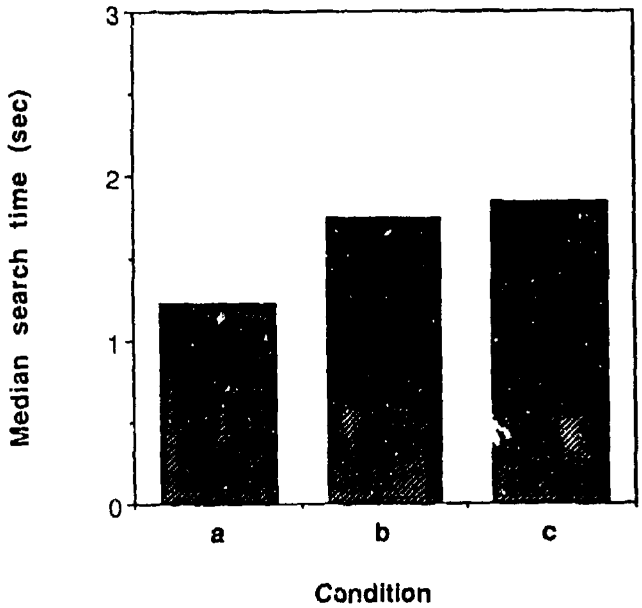

Fig. 8. Median search times (mean of four subjects) in Experiment 3. a. 100% overlap. b. 50% overlap - no brightness matching. c. 50% overlap - brightness matching.

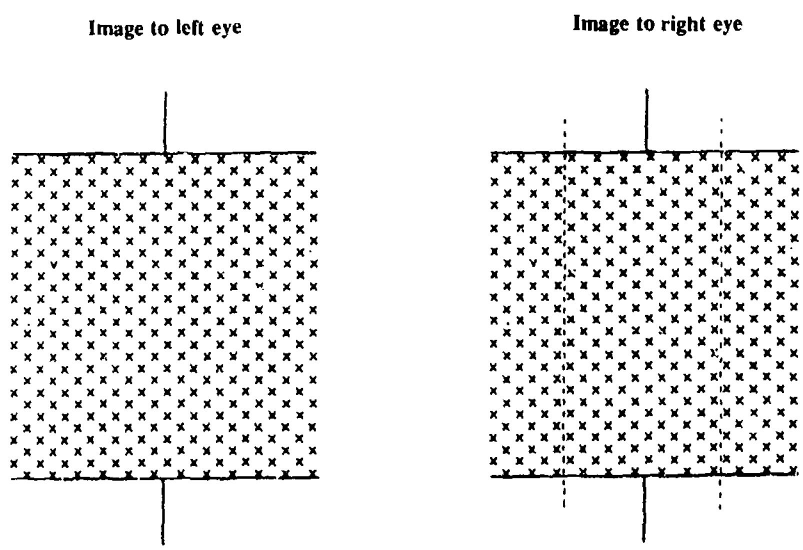

Fig. 9. Images presented in Experiment 4. The array of Xs between the broken lines was shifted to one side to give a binocular disparity between that portion of the two images.

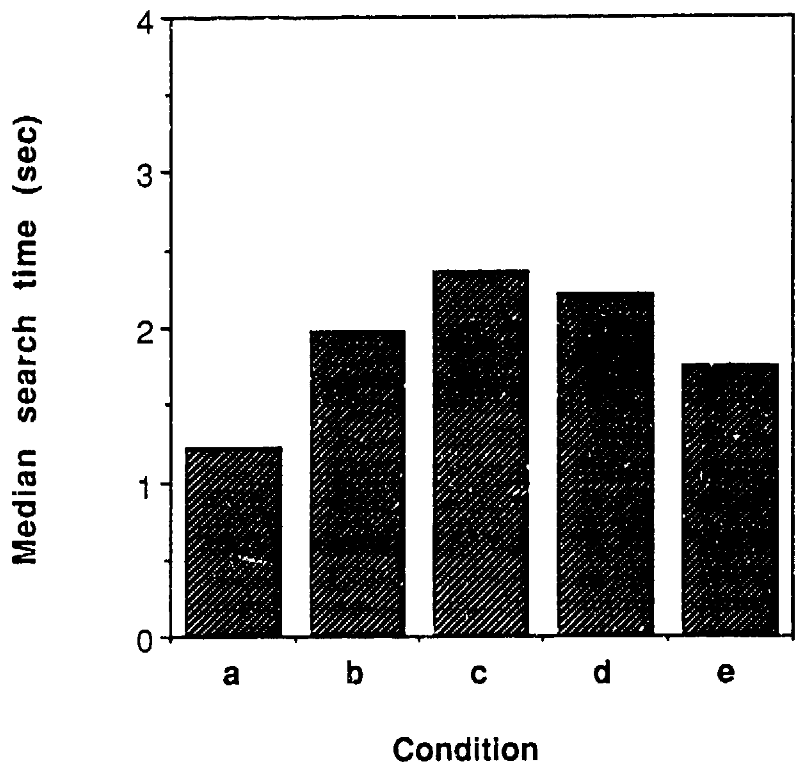

Fig. 10. Median search times (mean of four subjects) in Experiment 4. **a.** Zero disparity. **b.** 0.093 deg disparity. **c.** 0.186 deg disparity. **d.** 0.279 deg disparity. **e.** 50% overlap condition (data from Experiment 3.) to allow comparison between overlap and disparity conditions.

RESTRICTION DU CHAMP DE VISION : INFLUENCE SUR LA COORDINATION OEIL-TETE PENDANT L'ORIENTATION VERS UNE CIBLE EXCENTREE

Patrick SANDOR, Alain LEGER *

LAMAS CEV F-91228 Brétigny sur Orge (France)

RESUME : La vision en champ visuel limité devient de plus en plus fréquente avec l'emploi de systèmes optroniques montés sur le casque. Les conséquences de la restriction du champ de vision sur les caractéristiques de la coordination oeil-tête ont été étudiées pendant une tâche d'orientation vers une cible ponctuelle excentrée. Trois tailles de champ binoculaires sont testées (20°, 70° et Champ libre).
Une cible ponctuelle est projetée sur un écran circulaire dans un plan horizontal passant par les yeux du sujet. Cette cible est présentée avec 3 différentes excentricités : 45°, 67°et 85°. Les tests sont menés selon deux modes : prévisible et semi-prévisible, où seule la latéralité (à gauche ou à droite) est indiquée. La non prévisibilité rallonge les latences d'acquisition. Elle s'accompagne d'une augmentation du nombre de saccades de regard. La vitesse moyenne du regard mais aussi les vitesses crête pendant les saccades semblent être maintenues constantes au moyen d'un ajustement continu des vitesses oeil et tête.
La limitation de l'amplitude des saccades oculaires liée à la restriction de vision n'est pas compensée par une utilisation de tout le champ disponible. Seul l'hémi-champ visuel ipsi-latéral au déplacement est en général utilisé.
En conclusion, les résultats montrent que la restriction du champ de vision modifie les comportements moteurs impliqués dans la coordination oeil-tête, surtout lorsque l'emplacement de la cible n'est pas prévisible. La connaissance des mécanismes mis en jeu peut éventuellement contribuer à l'optimisation de l'emploi des dispositifs optroniques montés sur casque.

1. INTRODUCTION

La généralisation de l'emploi des aides à la vision portés sur le casque, et des interfaces Homme-Machine fondés sur des dispositifs optroniques coordonnés aux systèmes d'armes va entraîner pour les personnels une situation de travail en condition de vision avec un champ limité. Cette limitation du champ de vision amène des perturbations importantes de l'organisation des mouvements oeil-tête et sollicite fortement la plasticité des sous-systèmes impliqués dans la coordination oeil-tête (GAUTHIER et coll., 1987).

L'orientation du regard vers une cible, mettant en jeu simultanément un mouvement des yeux, de la tête et quelquefois même de tout le corps est un comportement banal. Les modèles classiques de l'orientation visuelle proposent que le contrôle du mouvement soit guidé par l'erreur rétinienne entre la position de l'image sur la rétine périphérique et la fovéa. Plus récemment, certains auteurs (BECKER et coll., 1981; GUITTON et VOLLE, 1987) ont proposé l'existence d'un contrôle préprogrammé du mouvement, arguant, en particulier, du problème de l'orientation vers une cible non visible, car trop excentrée au moment de l'initiation du mouvement. La limitation de champ visuel amène une situation expérimentale susceptible d'intervenir directement dans la stratégie de pointage vers une cible invisible au départ, dont la position est plus ou moins connue.

Les théories de l'attention visuelle (BUNDESEN, 1990) montrent qu'une information préalable sur la localisation d'une cible permet au sujet d'augmenter sélectivement son niveau d'attention sur tout élément situé dans la zone désignée. De ce fait, l'information préalable de localisation de la cible permet d'augmenter la précision du geste et diminue la latence d'exécution. Inversement, une information préalable incorrecte dégrade la performance du sujet.

Dans un article précédent (SANDOR et LEGER, 1990), a été mis en évidence l'effet, sur une tâche de poursuite d'une cible ponctuelle au mouvement prévisible, de 3 amplitudes (20°, 70° et champ plein) de champ visuel.

La présente étude avait pour objectif de tester les effets des mêmes valeurs d'amplitude du champ de vision dans une tâche d'orientation vers une cible latéralement excentrée.

2. METHODES

2.1 Dispositif expérimental

La plate-forme expérimentale est identique à celle décrite antérieurement (SANDOR et LEGER, 1990) :
Une cible ponctuelle rouge (1/4° environ) est projetée par un système Laser Hélium-Néon sur un écran hémisphérique de 1,80m de diamètre. Le sujet est assis sur un siège fixe et est fermement maintenu par un harnais thoracique. Sa tête est au centre de l'écran hémisphérique. La cible est projetée sur l'écran dans le plan horizontal passant par les yeux du sujet.

Dispositif de tête : Il comprend les système de mesure et de restriction du champ de vision :
Le sujet porte une coquille plastique adaptée au crâne par du tissu chardon. Au sommet est fixé un potentiomètre relié au siège par un mécanisme de cardans. Seul le mouvement de rotation de la tête autour de l'axe vertical est mesuré. Les mouvements oculaires horizontaux sont mesurés par Electro-Oculo-Graphie classique.
Un dispositif de restriction visuelle binoculaire est installé sur des lunettes d'essais; trois tailles de champ sont testées (20°, 70° et Champ libre où le sujet ne porte pas de lunettes).

2.2 Protocole

Sujets :

8 sujets ont participé à l'expérience. Un sujet, myope, est corrigé par le port de lentilles cornéennes souples depuis plusieurs années. Tous les autres ont une acuité visuelle 10/10.

Tâche expérimentale :

Il s'agit d'une tâche déclenchée de précision de pointage du regard. Le sujet reçoit un signal préparatoire, verbal, apportant une information préalable dépendant de la condition expérimentale, puis un signal de réponse visuel et auditif, qui indique au sujet de pointer son regard le plus rapidement possible.

Conditions expérimentales :

Deux conditions expérimentales sont proposées, portant sur l'information préalable contenue dans le signal préparatoire:
- **Condition prédictive** : le message verbal informe le sujet de la latéralité (Gauche ou Droite) et de l'excentricité de la position de la cible quand sera déclenché le signal de réponse qui va suivre. 3 valeurs d'excentricité seulement sont possibles, 45°, 67° et 85°, mémorisées par le sujet au cours de séances d'entraînement préalablement aux essais.
- **Condition non prédictive** : le message verbal n'informe que sur la latéralité. Aucune indication d'excentricité n'est donnée, parmi les trois possibles.

Chacune des 3 tailles de champ visuel fait l'objet d'une session expérimentale.

Consignes expérimentales :

En position initiale, le sujet regarde devant lui une LED rouge qui indique la position 0°. Le signal préparatoire est envoyé. Dans un délai variable aléatoirement entre 2 et 4 s, le signal de réponse, associant extinction de la LED centrale et Bip sonore, indique au sujet d'exécuter la tâche de pointage.

Chaque sujet effectue 6 sessions expérimentales. Chaque session voit la succession aléatoire de pointages selon 2 latéralités (Gauche ou droite) et 3 excentricités (45°, 67°, 85°): chaque configuration étant répétée 4 fois, une session comporte 24 essais.

*Now at SEXTANT-Avionique, Rue Toussant Castros, BP 91, 33166 St Medard en Jalles, Cedex.

3. RESULTATS

3.1 Influence de l'information préalable sur les latences d'acquisition.

L'ensemble des résultats concernant le mouvement de la tête et de l'oeil est caractérisé par une grande variabilité inter et intra-individuelle. Toutefois, certaines caractéristiques peuvent être exposées La condition champ visuel complet est ici prise comme condition de référence.

Les différents tracés présentent, en fonction du temps, le déplacement de la tête (t) par rapport à la pièce d'expérience, de l'oeil (o) par rapport au crâne, et par construction oeil + tête, du regard (r) par rapport à la pièce.

La figure 1 présente un exemple d'orientation en mode prédictif. Que la cible soit peu excentrée (figure 1a) ou très excentrée (figure 1b), le positionnement du regard est quasi direct. Une saccade oculaire initie le mouvement du regard 200 ms environ après le signal de réponse (qui coïncide avec le début du tracé). Le mouvement de la tête débute 50 ms après celui des yeux. Il se produit alors une immobilisation rapide de l'oeil, dont la position marque un plateau (plus appuyé sur la figure 1b), tandis que le regard (sommation oeil + tête) reste mobile et conserve une vitesse quasi stable (caractérisée par la pente du tracé). Quand le regard arrive aux abords de la position mémorisée de la cible, sa stabilisation est assurée par le réflexe vestibulooculaire (VOR), jusqu'à l'immobilisation de la tête.

La variabilité interindividuelle des stratégies d'orientation est accrue en cas d'incertitude de la position attendue de la cible. La figure 2 montre, chez deux sujets différents, la stratégie adoptée pour atteindre une cible située à 67°. L'un (figure 2A) procède par saccades de regard successives similaires en durée, amplitude et vitesse maximale. La vitesse de la rotation de tête est basse (50°/s) et presque constante. Le tracé oculaire montre un retour de l'oeil à la position 0° entre chaque saccade; ce retour semble là aussi conduit par le VOR. Le plateau observé entre la 2ème et 3 ème saccade de regard est positionnée à 45°, qui est une des trois position possibles de la cible; la dernière saccades est directye sur la cible à 67°. Le départ des mouvements oculaires et céphaliques sont simultanés, 300 ms après le signal de réponse. L'autre sujet procède différemment. Son regard va directement en position 67°, position intermédiaire parmi celle proposée. Sur la figure 2b, l'orientation est directe vers 67°. Une unique saccade oculaire de 4 à 5° vient parfaire le positionnement du regard. Quand ce même sujet (figure 2c) procède vers une cible non prédictive située à 45°, il la dépasse et exécute une saccade oculaire centripète très précise de 20° environ. Chez ce sujet, les latences au démarrage sont de 250 ms pour l'oeil et 300 ms pour le tête. Le plateau du mouvement du regard dure 400 ms avant la saccade de correction. Après immobilisation du regard sur la cible, là encore, le VOR assure le contrôle final du pointage pendant que la rotation de la tête s'achève.

3.2 Influence de la restriction du champ de vision sur la coordination oeil-tête

Il apparaît là également une grande diversité de comportement entre les sujets, en particulier dans le nombre des saccades oculaires produites. Toutefois, il semble que chaque sujet se tienne à une stratégie particulière et en change peu.

3.2.1 En mode prédictif

Sur la figure 3 est présenté un exemple de la stratégie employée par la plupart des sujets pour les trois différentes excentricités (figure 3a : 45°; figure 3b : 67°; figure 3c : 85°) quand ils disposent d'un champ de vision très étroit (20°). Les traits en pointillé indiquent le déplacement des limites du champ visuel disponible. Il est reconstruit à partir du tracé de la tête, augmenté et diminué de la valeur de la restriction appliquée (ici 10°). Il apparaît clairement que, dans les premières 50 ms après le début du mouvement, le regard est dirigé hors du champ de vision disponible, où il reste pendant 200 ms environ. Quand le regard arrive aux alentours de la position de la cible, il repasse à l'intérieur du champ disponible. A ce moment le sujet exécute une ou deux saccades oculaires visuellement guidées.

Quand le champ disponible s'élargit à 70° (figure 4), les caractéristiques de la coordination oeil-tête sont peu modifiées. Le regard passe cependant rarement hors du champ disponible, mais le délai d'acquisition de la cible est légèrement raccourci.

3.2.2 En mode non-prédictif

L'absence de prévisibilité de la cible, associée à la restriction visuelle, transforme profondément les stratégies déployées par les sujets. La figure 5 montre un exemple d'orientation vers un cible excentrée à 85°, quand le sujet dispose de 20° de champ. Le regard montre une succession très rapide de saccades entrecoupées de plateaux très bref, de 80 à 120ms. Chez ce sujet, seul le champ oculaire ipsi-latéral au déplacement vers la cible est utilisé pendant les saccades. Ce point est fréquent dans notre expérimentation, mais non systématique. Le regard reste dans le champ de visibilité, sitôt que son déplacement excède 20°. La vitesse moyenne du regard, caractérisée par la pente globale du tracé, reproduit les variation du déplacement de la tête. Toutefois, la vitesse pic pendant chaque saccade oculaire, semble rester dans le même domaine, ce qui indique que la vitesse oculaire maximale pendant la saccade est en rapport avec la vitesse de la tête. Le délai d'acquisition de la cible dépasse 1 s.

L'exemple de ce sujet est caractérisé par un nombre très important de saccades oculaires. Les autres sujets présentent les mêmes caractéristiques, mais exécutent moins de saccades (5 au maximum).

Quand le champ visuel augmente, les sujets peuvent être caractérisés selon qu'ils utilisent ou non le champ disponible. Sur la figure 6a (champ disponible 70°), le sujet procède comme s'il n'avait que 20° de disponible. Sur la figure 6b, cet autre sujet utilise au contraire une part plus importante du champ disponible; aucun des sujets dans cette condition non prédictive utilise tout le champ disponible. Le délai d'acquisition reste très supérieur à celui observé en condition champ libre.

La figure 7 présente un tracé où le sujet a manqué sa cible. C'est un exemple de comportement de recherche, associant saccades et périodes d'arrêt du regard, couplant les mouvements de l'oeil et de la tête par un mécanisme apparenté au VOR.

DISCUSSION

Le type de tracé observé en condition prédictive (figure 1) a été le plus souvent décrit dans le cas d'orientation vers des cibles peu excentrées (<40°) (BIZZI et coll., 1981; ROUCOUX et coll., 1981). Le contrôle final du mouvement est assuré par le VOR. Le plateau observé dans le mouvement oculaire (figure 1b) correspond à une phase de mobilité du regard, porté par le mouvement de tête. L'explication du contrôle de cette phase est controversée, certains auteurs pensent à une suppression, d'autres à une inhibition du VOR. Le contrôle initial n'est pas basé sur l'erreur rétinienne, la cible étant invisible au départ. La rapidité de positionnement du regard aux abords de la cible repose sur une préprogrammation du mouvement (BECKER et coll., 1981). La précision et l'absence d'hypométrie des saccades successives observées figure 2a peuvent être rapprochées de leurs observations.

Les modifications de la coordination oeil tête observées en condition non prédictive dépendent du choix stratégique du sujet. Le tracé observé en figure 2b conforte l'opinion souvent admise de l'hypométrie (10% environ) de la première saccade d'orientation, suivie par une saccade de correction (PRABLANC et coll., 1978). Dans le protocole suivi, la position de la cible ne peut avoir que trois valeurs. La préprogrammation du mouvement semble probable. La saccade oculaire de correction, de grande amplitude et en sens opposé à la première saccade, observée figure 2c est précédée par un long plateau de la position du regard. Cette durée pourrait refléter un temps minimal pour les mécanismes de prise d'information et de décision, en particulier liés au changement d'hémisphère cérébral (KAPOULA et ROBINSON, 1986). Ces auteurs ont montré l'existence d'un contrôle précis de l'amplitude de la saccade, dépendant du sens et de l'amplitude: Une saccade centripète est d'autant plus précise qu'elle est large. Pour une saccade centrifuge la précision est maximale pour des saccades de 6° d'amplitude environ, en deçà la saccade est hypermétrique, au-delà hypométrique. Les saccades de correction visuellement guidées nécessitent aussi l'annulation des saccades préprogrammées, d'où une augmentation des latences. Toutefois en

condition tête libre, la controverse demeure quant au contrôle des saccades de regard. Pour ROUCOUX et coll. (1981), le contrôle vers une cible située hors du domaine du champ oculomoteur est basé sur l'hypothèse de la suppression du VOR pendant la saccade. Cette hypothèse est très unanimement acceptée aujourd'hui, et les études les plus récentes sur les aspects neuronaux de la coordination oeil-tête la confirment (PARE et GUITTON, 1990). Nos résultats montrent cependant l'importance de la tâche assignée sur le mode du contrôle du déplacement du regard. Cet aspect élargit les observations de BECKER (1989), qui souligne l'importance des conditions de déclenchement d'une saccade sur ses caractéristiques. Dans nos conditions expérimentales, le VOR demeure actif pendant la saccade quand le champ visuel est réduit, et d'autant plus que la position de la cible est inconnue au départ du mouvement.

Il apparaît donc que. comme le souligne STEIMAN et coll. (1990), l'étude des mouvements de coordination oeil-tête met en jeu des mécanismes où l'influence de l'aspects cognitif de la tâche est primordial. Ce point semble prendre encore plus d'importance en réduisant le champ de vision. Il semble exister dans notre étude au moins deux types de sujets : Les uns ont un comportement de scanning rapide, avec persistance de l'effet modérateur de VOR sur l'amplitude de la saccade. Chez ces derniers, l'utilisation préférentielle de l'hémi-champ orbitaire ipsi-latéral au sens de la saccade est à rapprocher des observation de couplage de la commande nerveuse des muscles oculomoteurs et des muscles rotateurs de la tête (ANDRE-DESHAYS et coll, 1989, 1991). Au contraire les sujets ayant un comportement basé sur le «pari» sur la position de la cible, ont un comportement plus «réfléchi». Sur le plan des mécanismes neurophysiologiques impliqués, cette dualité dans le mode de commande des mouvements d'orientation du regard a été proposées par PAILLARD (1987) et plus récemment par PIERROT-DESSEILLIGNY (1989). Deux zones cérébrales seraient impliquées, les champs oculomoteurs frontaux (Frontal eye field FEF) et le Superior Colliculus (SC). L'activation des champs frontaux seraient essentiellement sous influence de la stimulation fovéale, tandis que l'activation colliculaire serait sous influence de la rétine périphérique. La restriction du champ de vision, outre la gêne dans la prise d'information qu'elle entraîne dans l'acquisition des informations visuelles, serait une entrave au mécanisme même de l'orientation du regard. Cet aspect a été évoqué récemment par SIVAK et Mc KENZIE (1990), dans l'étude du pointage du bras en condition de restriction visuelle.

ASPECTS PRATIQUES

La restriction du champ de vision étant une condition opérationnelle fréquemment rencontrée, l'une des demandes majeures des utilisateurs, en dehors du contenu informationnel qui peut être apporté par les différents visuels, est l'agrandissement du champ visuel disponible. En dehors des problèmes de coût que la satisfaction d'une telle demande entraîne, il apparaît intéressant de constater la très grande diversité avec laquelle les sujets réagissent aux variation de taille du champ. Si on ne se préoccupe que de l'utilisation du champ éventuellement accru, il semble que les sujets n'utilisent pas de manière optimale le champ proposé. Toutefois, le dernier point soulevé, quant à l'importance du champ visuel périphérique dans les mécanismes mêmes du contrôle de l'orientation du regard, montre l'importance du contenu informationnel concernant la cible désignée. Quand ce contenu est appauvri (situation tendue, charge de travail élevée), l'obligation d'agir en champ visuel très réduit peut prendre une importance que l'usage en condition «détendue» ne laisse pas prédire.

CONCLUSION

L'absence d'information préalable sur la position d'une cible modifie profondément les coordinations oeil-tête mises en jeu. Les choix de stratégie d'orientation varient selon le sujet. La restriction du champ de vision modifie profondément les stratégies d'orientation employées. Même en champ très restreint, les sujets n'emploient pas toute l'intégralité du champ disponible. L'élargissement du champ à 70° s'accompagne chez la plupart des sujets d'une augmentation modérée du champ oculomoteur. La restriction du champ de vision pourrait agir sur deux niveaux, l'un par la limitation de l'information visuelle, l'autre par l'action directe sur les mécanismes du contrôle de l'orientation du regard.

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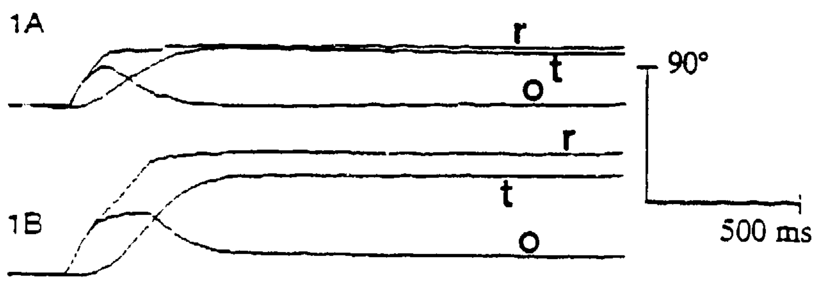

Figure 1 : Orientation vers une cible mémorisée avec information préalable de position
(o position de l'oeil dans l'orbite; t position de la tête et r position du regard
par rapport à la pièce d'expérience)

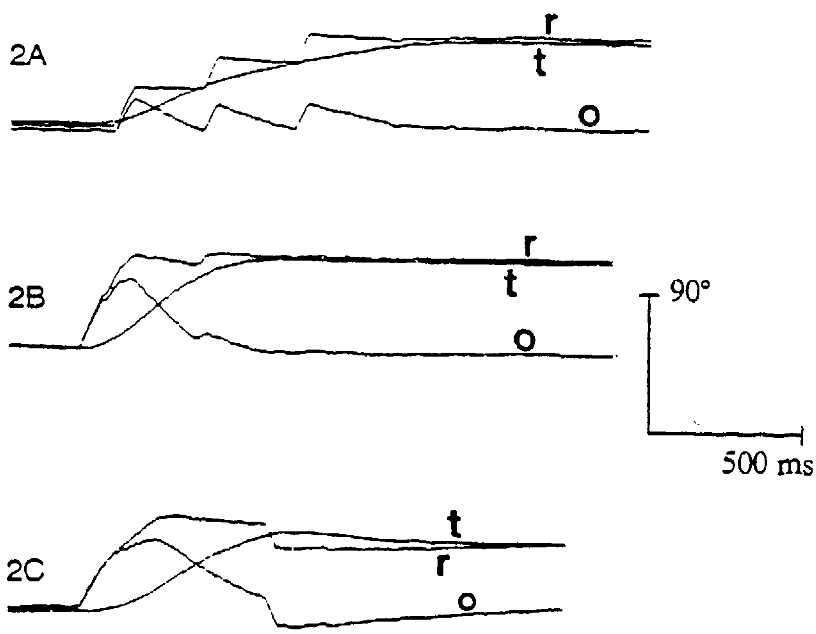

Figure 2 : Orientation vers une cible mémorisée sans information préalable de position
(Légende identique à figure 1)

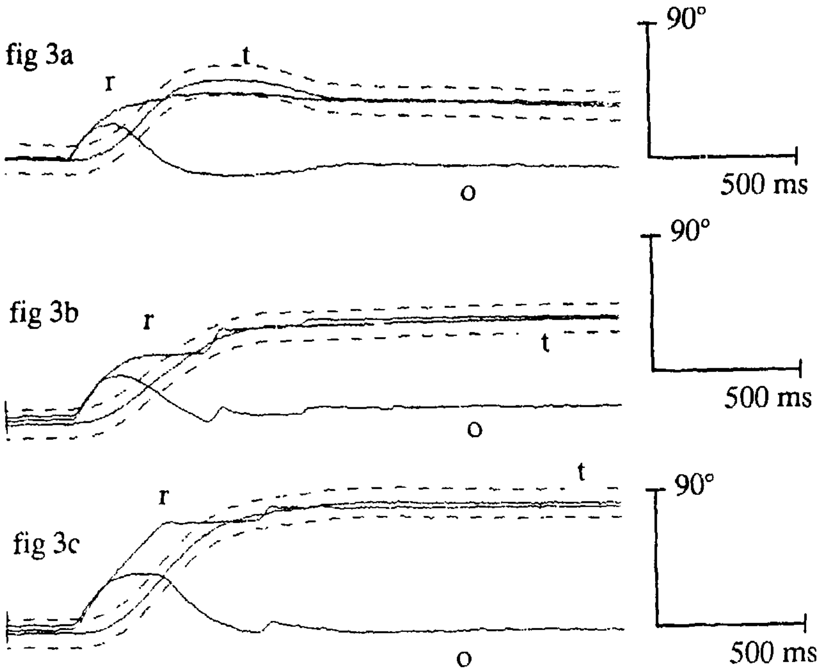

FIGURE 3 : Exemples de coordination oeil-tête en mode prédictif et 20° de champ de vision disponible pour 3 différentes excenticités de cible (fig 3a : 45°; fig 3b : 67°; fig 3c : 85°)

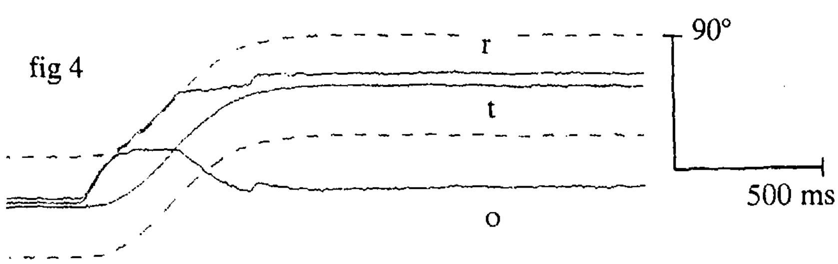

FIGURE 4 : Exemple de coordination oeil-tête en mode prédictif et 70° de champ de vision disponible.

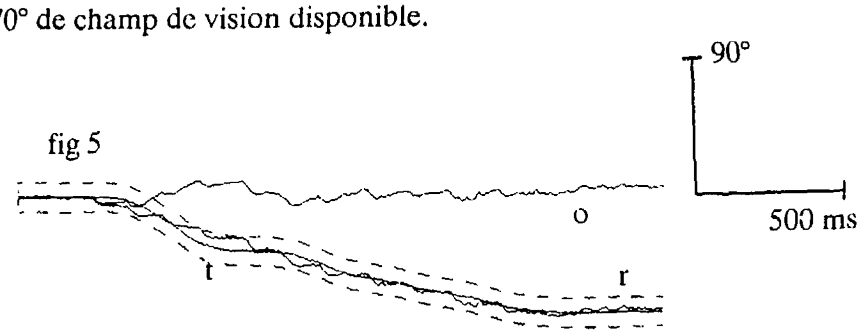

FIGURE 5 : Exemple de coordination oeil-tête en mode non prédictif et 20° de champ de vision disponible.

fig 6a

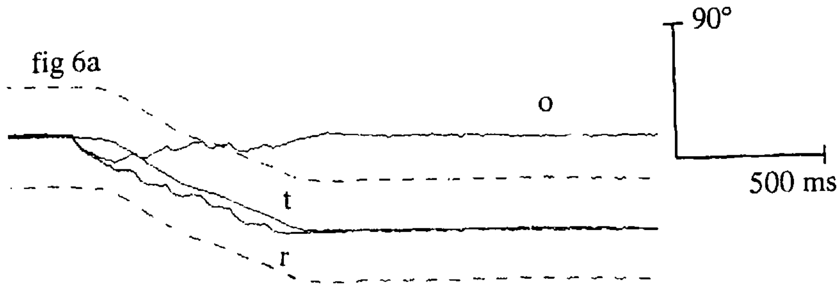

FIGURE 6a : Exemple de coordination oeil-tête en mode non prédictif et 70° de champ de vision disponible. Le sujet n'utilise qu'une partie du champ disponible

fig 6b

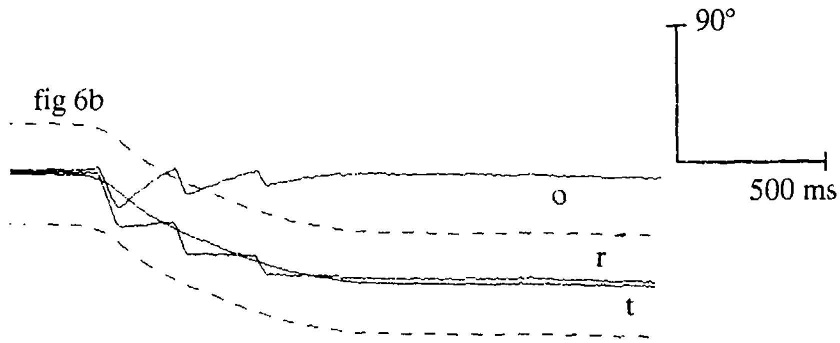

FIGURE 6b : Exemple de coordination oeil-tête en mode non prédictif et 70° de champ de vision disponible. Le sujet utilise plus largement le champ disponible.

fig 7

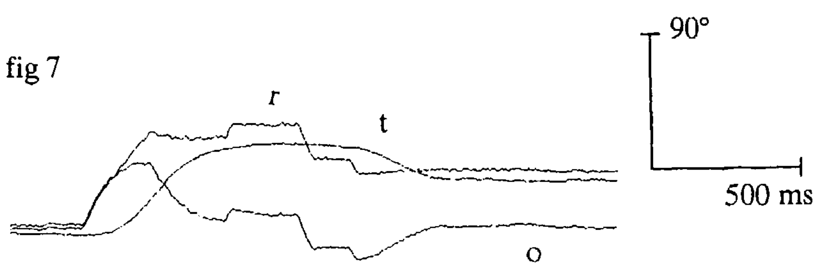

FIGURE 7 : Exemple de coordination oeil-tête en mode non prédictif et champ de vision complet. Le sujet procède à une série de saccades oculaires. On note que le mouvement de la tête est très faible tant que le regard n'est pas encore posé sur la cible.

The Effect of Field-of-View Size on Performance of a Simulated Air-to-Ground Night Attack

Robert K. Osgood
Armstrong Laboratory
Human Engineering Division
Visual Display Systems Branch
Wright-Patterson Air Force Base, OH 45433-6573

Maxwell J. Wells
Logicon Technical Services, Inc.
P.O. Box 317258
Dayton, OH 45431-7258

SUMMARY

Five experienced fighter pilots flew a simulated, night attack, pop-up bomb delivery, with a flight simulator that had a head-mounted display. The mission was conducted with an aircraft-fixed forward looking infrared sensor (FLIR) or a head-steered FLIR. With the head-steered FLIR, the sensor image was viewed on a helmet-mounted display, whereas the aircraft-fixed FLIR was presented on a HUD. With both types of sensor, the FOV with which the subjects could see the outside world was varied from 20 to 80 degrees. The purpose of the experiment was to explore the mechanisms by which field-of-view (FOV) size may affect performance, and to provide data for the determination of the minimum FOV size for helmet-mounted displays (HMDs). With a head-steered sensor, subjects acquired the targets earlier in the mission (7.88 sec after pop-up vs 13.86 sec), and released their bomb at a higher altitude (1084 vs 902 ft). Increasing the size of the FOV also resulted in earlier target acquisition (7.05 sec with an 80 deg head-steered FOV, 9.55 sec with a 20 deg FOV), and higher altitude releases (1175 ft vs 843 ft). It is explained how early target acquisition allowed subjects to modify their flight paths and so position their aircraft for higher releases. Using the times to find targets as the criterion, HMD FOVs of 20 and 30 degrees were significantly worse ($p<0.05$) than FOVs of 40, 60 or 80 degrees.

1 INTRODUCTION

One aid to flying at night is a Forward Looking Infrared sensor (FLIR). With current systems, objects outside the cockpit are imaged by the FLIR and viewed inside the cockpit on a panel-mounted display. A night vision system currently under development utilizes a head-steered FLIR, with the images viewed on a helmet-mounted display (HMD). This arrangement provides a more natural method for pilots to view the flight environment. A concern with the proposed new arrangement is the effect on performance of the size of the field-of-view (FOV) with which the pilot can see the outside world.

The issue of FOV size can be considered to consist of three variables (angular resolution, FOV size and weight) which combine in the following manner: Increasing the FOV of the HMD will, for a FLIR image with a fixed number of raster lines, decrease the angular resolution (number of raster lines per degree) of the image seen by the operator. Increasing the FOV size of the HMD will also increase its weight. Decreased angular resolution, decreased FOV size, and increased weight are all considered to adversely affect performance.

The inter-relationship between these three variables is inescapable in the design of an operational FLIR-based night vision system. To quantify the effect of one of the variables (FOV size), an experiment was conducted in the laboratory in which the other two variables (weight and angular resolution) were held constant. The manipulation of FOV size was accomplished by producing an image of constant angular resolution and electronically masking it to the appropriate size. The experiment measured performance at a typical mission for which the night vision system may be used; a low-level bomb delivery. For purposes of comparison, the experiment also investigated the effect of varying the FOV of the currently used arrangement of a panel-mounted display and aircraft-fixed FLIR.

The effect of FOV size on performance with HMDs has been addressed previously, using a simple target-finding task (Ref. 1) and with simple simulations of air-to-air tasks (Refs. 2, 3, 4). Performance at a more complex air-to-ground simulation has also been investigated (Ref. 5). However, the purpose of that study was to test the efficacy of a simulator, and FOVs were used which were much larger than those which are feasible for use on a flight-worthy HMD. The effect of realistic FOV sizes on performance at the sort of mission for which the systems will be used, has never been reported.

2 METHOD

2.1 Subjects

The experiment was conducted with five USAF F-16 pilots (mean flight time 2350 hours). All pilots had flown air-to-ground missions, and, in addition, one had flown with a prototype head-steered FLIR and HMD system.

2.2 Apparatus

The study was conducted in the Visually Coupled Airborne Systems Simulator (VCASS). The facility consists of a binocular HMD, an electromagnetic helmet

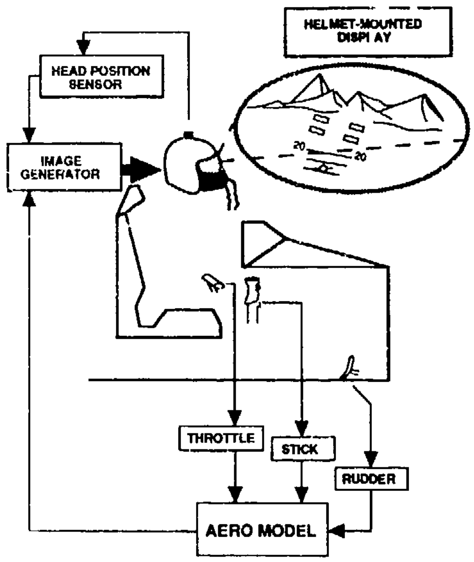

Figure 1. Diagram of the components of the Visually Coupled Airborne Systems Simulator (VCASS). The throttle, stick and rudder were located in a mock-up of an aircraft cockpit.

position sensor and a digital image generator (Figure 1). The maximum FOV of the VCASS HMD is 120 degrees horizontally by 80 degrees vertically. Subjects wore the HMD, which occluded their view of the outside world. Instead, they saw computer-generated images (virtual images) appropriate to their sitting inside the cockpit of a fighter aircraft, while flying over a gaming area 174 nautical miles (nm) square. The helmet position sensor updated the image generator, so that the scene on the HMD was appropriate to where the pilot was pointing his head. The cockpit had a HUD, with symbology subtending 20 degrees horizontally and vertically. In the aircraft-fixed sensor conditions, the subject could only see out of the cockpit by looking through the HUD, the FOV of which was the same as the aircraft-fixed FLIR. In the head-steered FLIR conditions, the subject could see outside the aircraft in all directions, except those obscured by the cockpit. Subjects used real controls (throttle, stick and rudder) to fly the simulated aircraft. The images on the simulator were updated at 10 Hz.

2.3 Procedure

The experimental task was a 10 degree-dive bomb-delivery. The parameters of the maneuver are shown in Figure 2. The target was one specified building among a group of four buildings. The buildings were not visible until the aircraft was within two nm of their position, or the aircraft was above 500 ft. Subjects were allowed a total of 30 seconds above 500 ft before they were struck by a missile (a message informed the subject they had been struck, but the trial continued). The approximate location of the target was indicated on the aircraft HUD, when it was switched to the Continuously Computed Release Point (CCRP) mode. In this mode, a vertical line indicated the direction in which the aircraft had to be steered to intercept the target, and a Target Designation (TD) box indicated the location of the target in azimuth and elevation. If the off-axis angle to the target exceeded the symbology area of the HUD (20 deg), the TD box pegged at the appropriate boundary, and a line extended from the center of the HUD to the TD box. As part of the experiment, there was a deliberate offset between the indicated and actual location of the target.

At 3.5 nm from the indicated location of the target, the subjects were supposed to "pop" (climb rapidly to above 500 ft) to an altitude of 2300 ft, acquire the buildings visually, and aim and release their weapon at the correct target. To release the bomb, subjects first switched the HUD from CCRP mode to Continuously Computed Impact Point (CCIP) mode. They then maneuvered the aircraft to overlay the CCIP pipper over the target, and pressed the bomb release switch. The subjects ended the trial when they were on a heading of 180 degrees and had flown 2.0 nm from where they dropped their bomb.

Subjects were instructed that if they executed a "pop" but were unable to deliver the weapon, they were to descend

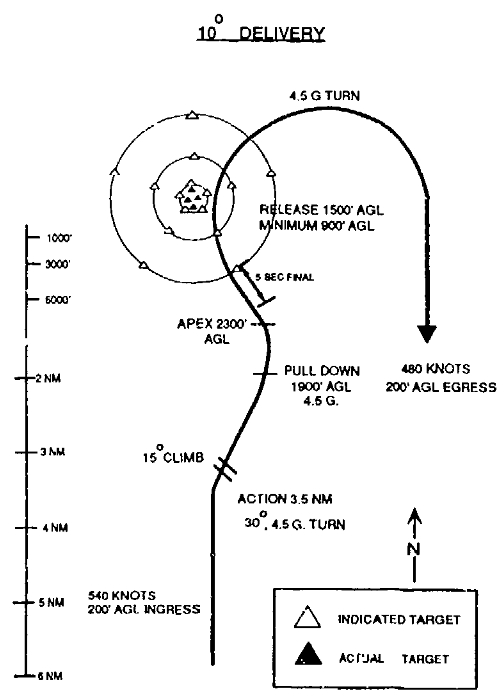

Figure 2. Parameters of the 10 deg-dive bomb-delivery used in the experiment. Subjects started 6 nautical miles (nm) south of an indicated target.

below 500 ft and attempt one more pass, at or below 500 ft, before ending the trial. Reasons for failure to deliver the weapon on the first pass included being unable to find the target, and not attempting to dive at the target, because doing so would have required too steep a dive angle. The trial ended if the subject flew into the ground.

The independent variables were FOV size (20,30,40,60,80 degrees in diameter), head-steered vs aircraft-fixed FLIR, actual target location (N,S,E,W), and indicated target location (5 bearings at each of 3 ranges; see Figures 2 and 3).

2.4 Experimental design

Each subject completed four sessions, one session per day. The first session consisted of a briefing and a minimum of 15 practice trials, with exposure to the range of FOVs, indicated target locations and sensor types. Subsequent sessions consisted of 15 head-steered or aircraft-fixed trials, followed by 15 aircraft-fixed or head-steered trials. The order of head-steered and aircraft-fixed trials was alternated across sessions. Odd-numbered subjects began with head-steered trials and even-numbered subjects began with aircraft-steered trials. The manner in which the FOVs were matched with target positions is shown in Figure 3. For each subject, the order of FOVs, indicated targets and actual targets remained the same for each set of 15 trials and across sessions 2,3 and 4.

3 RESULTS

The experiment produced more data than can be presented in this paper. Sufficient results will be presented to attempt to explain how subjects responded during the experiment and, based on this, tentative recommendations will be made on minimum FOV requirements. Further analysis of the data will be presented in future reports.

Only the data from the first passes from sessions 3 and 4 will be presented in this paper. The dependent variables included aircraft position and orientation, bombing performance, pilot head movement and times at which the pilot performed certain maneuvers. Figure 4 shows idealized altitude profiles for head-steered and aircraft-fixed trials with illustrations of some of the dependent variables. Target sighting was indicated by the subject pressing a button on the control stick.

Figure 5 shows altitude profiles for subject 3, using a 40 degree FOV with a head-steered and aircraft-fixed sensor. The target had a medium offset (number 10 from Figure 3) and the data were collected in session 4. The head-steered profile illustrates the following: (1) a 4.5 g turn to the right at about 18 seconds, followed by an above 3 g pull-up; (2) a large head movement at about 27 seconds, which resulted in a target sighting at 30 seconds; (3) tracking of the target by the head, between 32 and 48

HEAD-STEERED OR AIRCRAFT-FIXED FOV — INDICATED TARGET POSITIONS

SUBJECT	20			30			40			60			80		
1	6	11	1	7	12	2	3	8	13	4	14	9	10	15	5
2	2	12	7	13	3	8	4	9	14	15	10	5	11	1	6
3	3	8	13	14	4	9	5	10	15	6	11	1	2	12	7
4	14	9	4	5	15	10	11	6	1	7	12	2	8	13	3
5	15	5	10	6	11	1	2	7	12	3	8	13	9	4	14

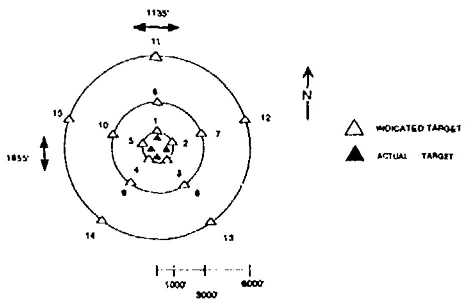

Figure 3. Diagram of the experimental design and the arrangement of the actual and indicated targets. Each subject was presented with the FOVs in a different random order. The indicated targets were matched with the FOVs as shown. Actual target positions were randomized for each subject.

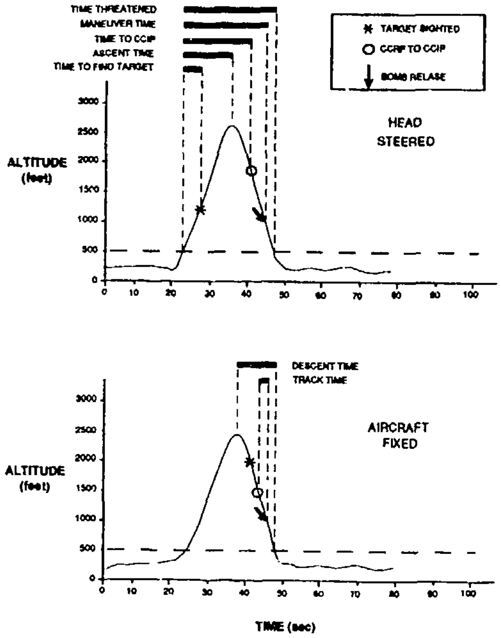

Figure 4. Idealized altitude profiles for both types of sensor, with illustrations of some of the dependent variables.

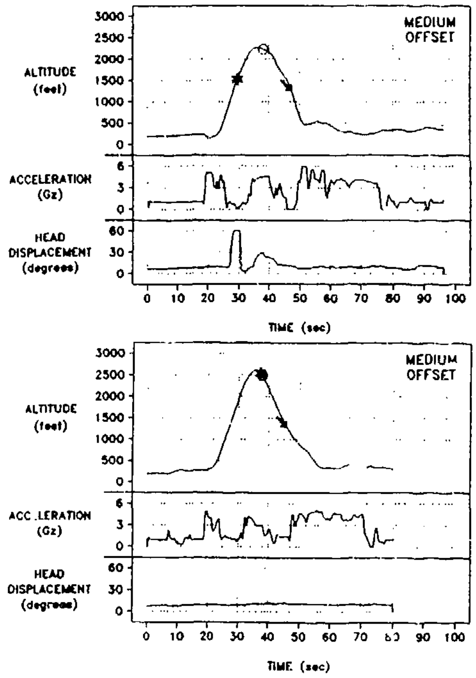

Figure 5. Altitude profiles for two trials with a 40 deg FOV head-steered (upper) and aircraft-fixed (lower) sensor. Subject 3, session 4.

seconds, as the pilot rolled the aircraft around his head, switched to CCIP, and lined up the HUD with the target (zero degrees head angle means the pilot's head was pointing straight ahead); (4) a greater than 6 g pull-up at about 51 seconds, following bomb release at 47 seconds. Figures 6, 7 and 8 show the mean data for the 5 subjects, across 2 sessions, for each FOV, type of sensor and target offset range.

The data were subjected to analysis of variance using a general linear model. The model partitioned out the variance due to sensor, FOV, target offset range and target offset bearing, and the interactions between these main effects. It should be noted that each subject experienced each FOV at 3 different target offset ranges, but only one target offset bearing (see Figure 3). Thus, within a subject, bearing was confounded with FOV. This was accounted for by dropping subject from the model. The variance due to subject was reallocated to the interactions involving bearing x FOV, which were uninterpretable. The P-Values o: 6 dependent variables are shown in Table 1. The main effects and interactions of target offset bearing will be presented in future reports. The results of post-hoc analyses of variance of the time-to-sight data are shown in Table 2.

4 DISCUSSION

Each mission consisted of four phases: ingress, target acquisition, aiming and egress. In the first phase, ingress,

P-Values

Source	Degrees of Freedom	Time to Find	Switch to CCIP	Maneuver Time	Release Altitude	Track Time	CCIP Altitude
Sensor	1	0.0001**	0.0001**	0.9365	0.0001**	0.0001**	0.0001**
FOV	4	0.0001**	0.0001**	0.0012**	0.0004**	0.0026**	0.0018**
S x F	4	0.2478	0.8077	0.8116	0.1740	0.1465	0.0163*
Range	2	0.0001**	0.0022**	0.0001**	0.1266	0.0001**	0.2996
S x R	2	0.0001**	0.0393*	0.1033	0.2116	0.9994	0.7365
F x R	8	0.0318*	0.4712	0.6207	0.6384	0.5076	0.3862
S x F x R	8	0.3890	0.8140	0.7248	0.4948	0.9013	0.5831

Table 1. Values from a fixed-effects general liner model analysis of variance *=P<0.05, **=P<0.001.

subjects relied almost entirely on their instruments. They were required to maintain a constant heading and altitude while increasing speed to 540 knots. At 3.5 nm from the target, they turned right 30 degrees and immediately went into a 15 degree climb. All of this could be accomplished by referring to the HUD. Performance in the ingress phase was consistent and did not appear to be affected by the type of sensor, FOV or target offset. The egress phase commenced after the subjects released the bomb, or if no bomb release occurred, after they passed the targets. During egress, the subjects were required to get below 500 ft and turn to the correct heading. Performance in this phase also appeared to be unaffected by type of sensor, FOV or target.

In the second phase, acquiring the target, the buildings became visible if they fell within the FOV of the sensor, and the aircraft was above 500 ft. In the aircraft-fixed trials this occurred infrequently during the ascent, and usually only with the largest FOVs. Mostly, the target was acquired at, or shortly after, the apex. With the head-steered sensor, subjects usually found the target earlier, before the apex. The mean times to find the target are shown in Figure 6. The changes in the time to find the target, caused by type of sensor and FOV, reflect the contributions of these two variables to this phase. The mean time to find the target across all the head-steered trials (7.88 sec) was 43% less than the mean of the aircraft-fixed trials (13.88 sec). The mean time to find targets with an 80 degree FOV in the head-steered trials (7.05 sec) was 26% less than with a 20 degree FOV (9.55 sec). The mean time to find targets with an 80 degree FOV in the aircraft-fixed trials (12.40 sec) was 18% less than with a 20 degree FOV (15.20 sec).

With a head-steered sensor, subjects used head movements to search the terrain for cues about the target location. Once they acquired the target, they also used head movements to track the target as they rolled the aircraft around their head. Although their view outside the cockpit provided information about spatial orientation and target location, they still needed to monitor the aircraft instruments. The competing demands of monitoring the HUD and the target suggest that the superimposition of some HUD information onto the FOV of the HMD might aid performance at some phases of the task.

Following target acquisition, the subject went to the aiming phase. The end of the aiming phase was marked by bomb release, which occurred at lower altitudes with the aircraft-fixed sensor and with smaller FOVs (Figure 7). In a real delivery, low bomb release would increase the possibility of fragmentation damage to the aircraft. The minimum release altitude was stipulated as 900 ft. The desired altitude was 1500 ft. Both of these minima were violated. The reason for these violations probably had to do with the nature of the aiming task and the update rate of the simulation.

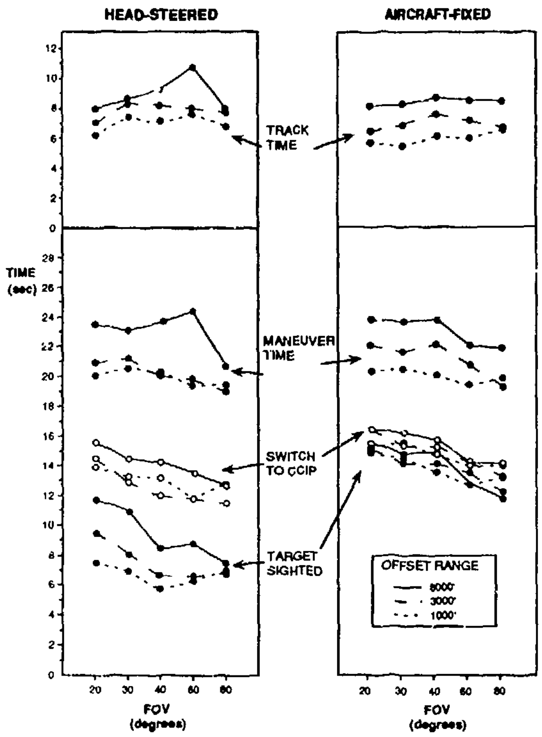

Figure 6. Mean data for 5 subject from session 3 and 4.

Specifically, the aiming phase may be subdivided into two parts. In the first part, the subject attempted to place the target within the FOV of the HUD. In the second part, the CCIP pipper was placed precisely over the target. The former part required gross aircraft movements, whereas the latter part required more precise control inputs. In the latter part, lags introduced by the simulation caused subjects to reduce their response speed. This probably contributed to longer tracking times (Figure 6) and lower release altitudes (Figure 7) than would have occurred with a real bomb release.

A simple hypothesis to expain the effects of sensor type and FOV size on release altitude is that early sighting of the target allowed earlier (and therefore higher) bomb release. If this were the case, the differences in the times at which the bombs were released (the maneuver times, Figure 6) would correlate with the release altitudes. A mean pitch axis angle at release of -6 degrees and a speed of 500 knots corresponds to a vertical velocity of 88 ft/sec. The difference between mean maneuver time with an aircraft-fixed sensor (21.4 sec) and a head-steered sensor (21.1 sec) is not only too small, but in the wrong direction, to explain the difference in mean release altitudes between the two sensors (902 ft and 1084 ft). Furthermore, the effects of FOV size and target offset produce different effects on the two dependent variables.

To understand what happened, it is necessary to consider the geometry of an air-to-ground attack. In order to successfully drop a bomb on a target, it is necessary for the aircraft to intersect, and point down, a line sloping up from the target. (The "line" is actually 3 dimensional, and describes the surface of a funnel with the target at the base). The slope of the line depends on the ballistic properties of the bomb and the required bomb impact angle. The further away from the target the aircraft can intercept the line, the higher it will be.

With an aircraft-fixed sensor, it is easy to understand the prerequisite conditions before a subject switched from CCRP to CCIP. Subjects only switched to CCIP after the target and the HUD were simultaneously visible within the FOV, otherwise, they lost what little information they had about target location provided by the CCRP TD box. It is likely that the impetus to switch was similar with a head-steered sensor. Switch to CCIP therefore indicates the achievement of a certain angular relationship between the target and the direction in which the aircraft is pointing, or in other words, an approximate intersection of the line. Following the switch to CCIP, the subjects used the pipper to precisely intercept the line. If the pipper was between the aircraft and the target, the aircraft was too low. If the target was between the aircraft and the pipper, then the aircraft was too high. The times to make the precise intersection (track times) were similar across FOV and type of sensor, which further supports the hypothesis that the switch to CCIP occurred only after an approximate intersection of the line. Figure 7 shows the mean altitudes at which the switch occurred. There was an increase in altitude with increasing FOV, and the switch occurred higher with a head-steered sensor than with an aircraft-fixed sensor. Apparently, the advantage of a head-steered sensor and a large FOV was that they allowed subjects to see the target earlier and make the necessary control inputs to intersect the line further from the target.

In this simulation, a high release may have been disadvantageous to bomb accuracy because of alignment errors in the apparatus. The HUD symbology and the target and terrain information were generated by different computers. The two sets of images were fused on the VCASS HMD. Any angular misalignment between the two images meant that what the subject aimed at through the HUD, and what the aircraft aimed at, were different. The effect of an angular misalignment increased with increasing altitude. Therefore, the increasing bomb error with increasing FOV in Figure 8 may be explained by the increasing release altitudes with increasing FOV in Figure 7. The sizes of the bomb errors correspond to a maximum angular error of about 1.5 degrees. It is likely that the misalignment was less than this. Other sources contributed to bomb error, including timing differences between the two computers (this was constant across all conditions).

Two issues emerged from the experiment concerning the minimum FOV size for HMDs. The first is that it was possible to perform the task irrespective of FOV size. The second is that a clear effect of FOV size was to alter how long it took to find the target. Target sighting led to a chain of events which culminated in higher release altitudes with larger FOVs. Based on target sighting times, 20 and 30 degree FOVs seem to stand out as being significantly worse than the larger FOVs when there was a large target offset (Table 2).

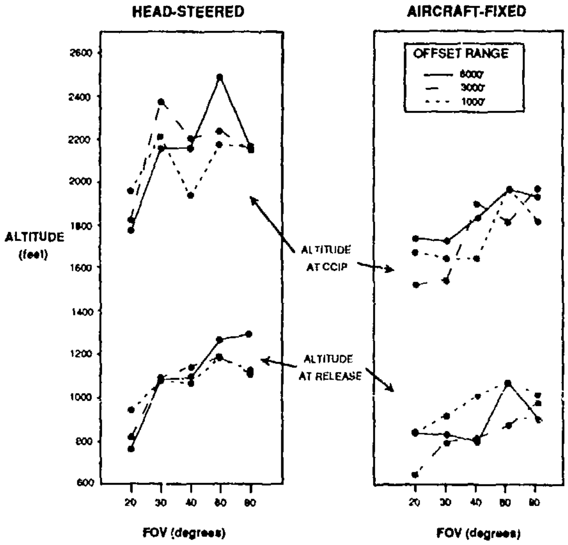

Figure 7. Mean altitude data for 5 subjects from sessions 3 and 4.

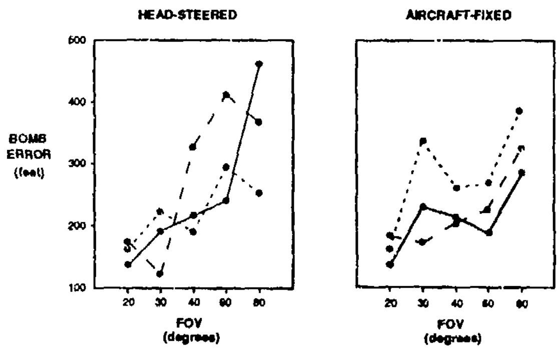

Figure 8. Mean bomb error data for 5 subjects from sessions 3 and 4.

TIME TO FIND TARGET

FOV (degrees)

FOV (degrees)	30	40	60	80	
20	0.998	0.011*	0.030*	0.165	
30		0.329	0.331	0.423	1000'
40			0.863	0.722	
60				0.726	

FOV (degrees)	30	40	60	80	
20	0.267	0.132	0.068	0.330	
30		0.505	0.267	0.893	3000'
40			0.677	0.448	
60				0.253	

FOV (degrees)	30	40	60	80	
20	0.027*	0.006**	0.031*	0.000**	
30		0.004**	0.014*	0.000**	6000'
40			0.290	0.343	
60				0.447	

Table 2. Probabilities of the means being different for times to find the target with different FOVs and target offset ranges. *=p<0.05, **p<0.001

5 CONCLUSIONS

1) The time it took to find targets affected subsequent performance of the bombing task, such that early sighting resulted in bomb releases at higher altitudes.

2) Targets were sighted earlier, and bombs were released higher, with a head-steered sensor than with an aircraft-fixed sensor.

3) The task could be performed with all FOV sizes.

4) With a head-steered sensor and a large target offset, it took significantly longer to find targets with FOVs of 20 and 30 degrees than with FOVs of 40, 60, and 80 degrees.

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L'AVENIR EST-IL AU VISUEL DE CASQUE BINOCULAIRE ?

Médecin des Armées Corinne ROUMES
Ingénieur Justin PLANTIER
Médecin en Chef Jean-Pierre MENU
Division Vision et Ergonomie
Centre d'Etudes et de Recherche de Médecine Aérospatiale
Base d'Essais en Vol - 91228 Brétigny sur Orge Cedex - France

Résumé

L'introduction d'une présentation binoculaire dans les visuels de casque ne peut pas seulement être considérée comme un simple rééquilibrage des stimulations visuelles entre les deux yeux compte-tenu des propriétés spécifiques de la vision binoculaire chez l'homme. Un nouveau support d'aide à la représentation de l'environnement par le pilote est disponible. Le bénéfice potentiel de viseurs binoculaires repose sur la transposition des capacités de traitement visuel aux conditions de génération et de restitution des images dans le visuel de casque. Les différents problèmes soulevés par ce transfert sont envisagés ; certains nécessitent des investigations expérimentales notamment pour déterminer la tolérance à la sollicitation partielle de la binocularité et aux contraintes de l'environnement aéronautique. Au vu de ces difficultés, la part de la binocularité dans un visuel peut être envisagée différemment dans la présentation d'images issues du monde réel par des capteurs ou de symbologie, dans le cadre d'un vol effectif ou de la simulation.

INTRODUCTION

Les conditions d'évolution dans un contexte aéronautique favorisent tout particulièrement la vision comme source d'information. Sa prépondérance sur les autres modalités sensorielles s'amplifie au fur et à mesure que la prise de conscience intéresse un environnement plus distant du pilote : prenant une large part dans l'orientation spatiale, elle constitue l'élément majeur de la perception du cadre géographique et de l'appréciation de la conjoncture tactique. Les informations visuelles, initialement scindées en leurs composantes élémentaires fonction de la sensibilité des capteurs oculaires, constituent un flux afférent en continu qui alimente et enrichit une représentation interne de la situation. L'adéquation de cette représentation avec l'environnement réel dépend d'une part d'un recueil adapté des afférences mais également d'un modèle d'intégration cohérent avec la situation. Ce modèle s'élabore progressivement avec l'apprentissage de la tâche de pilotage ; la présentation de l'information sous la forme la plus accessible au système visuel en tenant compte de ses caractéristiques physiologiques peut prétendre optimiser le flux d'afférences. De ce fait, le visuel de casque représente un support de choix pour réaliser une aide au pilote dans sa représentation de la situation.

Le visuel de casque s'est progressivement imposé comme une nécessité opérationnelle dans l'équipement du pilote. Le bénéfice immédiat attendu en est double : i) dans sa fonction viseur de casque, c'est faciliter la communication homme-système ; ii) dans sa fonction support de visualisation, c'est rendre l'information disponible quelle que soit la position du regard.

Les premières mises au point technologiques ont conduit à l'élaboration de visuels monoculaires. Ceux-ci se sont avérés délicats d'emploi notamment parce que, du fait de la rivalité entre les deux yeux stimulés si différemment, l'image support d'information a tendance à être neutralisée occasionnellement. La solution est alors suggérée dans l'introduction de visuels binoculaires.

Au vu des considérations sur la représentation de la situation, la réponse n'est pas aussi immédiate car la vision binoculaire joue un rôle qui lui est propre tout particulièrement dans la vision du relief. Les deux images très légèrement différentes issues des deux yeux constituent des afférences dont la comparaison donne une information sur les distances dans l'espace analysé.

La simple présentation de deux images strictement identiques aux deux yeux dans un visuel de casque tenterait de s'affranchir des capacités d'analyse binoculaire dans cette perception des distances. C'est manquer l'apport d'une information potentielle dans l'intégration de la situation. Ce manque est d'autant plus préjudiciable que la perception de relief d'origine binoculaire est issue d'un traitement très primitif et immédiat. A l'inverse, les éléments monoculaires de l'appréciation du relief reposent sur un traitement de l'information visuelle beaucoup plus élaboré où l'apprentissage de l'interprétation des formes joue un grand rôle.

Par contre, choisir d'exploiter la binocularité dans un visuel de casque suppose de présenter des stimulations visuelles adaptées à sa mise en oeuvre. La négligence de ses spécificités ou une mauvaise sollicitation risqueraient de créer plus de problèmes qu'il n'en serait résolu.

En effet, les capteurs oculaires ont un certain nombre de caractéristiques en localisation, champ visuel et mobilité de sorte que dans la partie traitement de l'information, les possibilités d'analyse du signal visuel (et la spécialisation fonctionnelle binoculaire) sont liées aux caractéristiques de ces capteurs. C'est

pourquoi l'aptitude binoculaire vérifie tout d'abord l'existence des conditions nécessaires au niveau des capteurs pour acquérir une information exploitable (propriétés optiques comparables, position des yeux, motricité binoculaire), mais aussi la résultante du traitement par la perception de profondeur dans des tests visuels binoculaires.

De grandes perturbations sont introduites dans cette chaîne de prise et traitement de l'information quand on passe de la vision binoculaire de l'homme à la mise en oeuvre de la binocularité dans un visuel de casque.
Dans le cas de la vision habituelle, un certain nombre d'éléments sont fixes : l'écart entre les capteurs, le champ visuel (sachant qu'il y a large recouvrement des champs monoculaires dans un grand champ binoculaire) ; d'autres sont adaptés à l'environnement au cours du temps : la vergence et l'accommodation. Ces derniers paramètres sont variables pour ajuster les conditions de prise de vue et permettre au traitement d'être pleinement efficace.
Dans le cas du visuel, sont fixes : le champ visuel (avec cette différence qu'il est nettement réduit avec le risque d'une transition centrale entre binoculaire et monoculaire en cas de recouvrement partiel), la mise au point (à l'infini) et la convergence des capteurs (toujours envisagée nulle en conditions réelles) ; éventuellement modifié : l'écart entre les capteurs.
Les conditions de prise de vue et leur adaptation au cours du temps sont éminemment différentes dans les deux configurations ce qui peut donner naissance à des difficultés d'interprétation des stimulations binoculaires.

Pour tenter d'apporter des éléments de réponse à l'intérêt de disposer d'un visuel de casque binoculaire dans l'aide à la représentation de l'environnement, une description est faite des avantages offerts par l'utilisation de la vision binoculaire dans les conditions physiologiques, puis les composantes de la vision binoculaire qui peuvent entrer en jeu dans les différents types de visuels de casque sont envisagées avant d'aborder les problèmes associés aux sollicitations plus ou moins partielles de la binocularité dans les visuels. Dans ces conditions, un certain nombre de propositions peuvent être dégagées.

1- APPORT DE LA VISION BINOCULAIRE

1.1- Sur les grandes fonctions visuelles

La prise en compte par les deux capteurs oculaires d'un même stimulus visuel améliore la perception résultante. En ce sens, la visualisation binoculaire, en se rapprochant des conditions usuelles de mise en oeuvre du système visuel, est supérieure à la visualisation monoculaire.

Cette amélioration a été mise en évidence au niveau des seuils de perception où le seuil lumineux absolu est abaissé, la fonction de sensibilité au contraste augmentée en rapport constant sur toute l'étendue des fréquences spatiales et l'acuité visuelle accrue (Réf.1, 2, 3, 4). Le bénéfice de la binocularité se manifeste encore au niveau de stimulus supra-liminaire avec par exemple une réduction du temps de présentation nécessaire à la reconnaissance de formes ou encore le raccourcissement du temps de réponse (Réf.5).

L'ensemble de ces améliorations est expliqué par la sommation des probabilités de détection et d'analyse du signal visuel reçu par chacun des deux yeux, mais également par une sommation neuronale au niveau des structures d'intégration des informations binoculaires qui augmente la sensibilité du système couplé par rapport à l'exploitation individuelle des capteurs. Ces effets ne s'expriment que dans la mesure où les structures codant le même type d'information sont simultanément stimulées dans les deux rétines (identité de localisation, d'orientation, contenu fréquentiel différant de moins d'une demie octave, décroissance de l'effet avec l'introduction d'un délai croissant entre les stimulations dédiées à chaque oeil...).

Outre l'amélioration des capacités fonctionnelles du système visuel, la vision binoculaire assure une augmentation du domaine spatial d'investigation. De part et d'autre de la zone centrale du champ visuel binoculaire où les deux champs monoculaires se superposent, les zones périphériques temporales explorées sélectivement par l'oeil homolatéral sont prises en compte. Ces dernières assurent un gain de champ visuel de 25 à 40° selon les auteurs (Réf.6,7,8). Néanmoins, l'utilisation de la binocularité permet toujours une extension du champ visuel total. La sommation des traitements peut s'effectuer dans la zone de recouvrement des champs visuels monoculaires. L'information est recueillie de façon monoculaire dans les croissants périphériques.

1.2- Spécificité binoculaire pour la perception du relief

La localisation des deux capteurs oculaires dans un plan horizontal frontal, avec un décalage lié à l'écart inter-pupillaire, a pour conséquence une légère différence des deux images rétiniennes. Cette différence est exploitée par le système visuel pour en déduire des informations strictement binoculaires déterminantes pour la perception du relief.

La dualité des capteurs a deux grandes conséquences : la stéréopsie et la distorsion binoculaire.

1.2.1- La stéréopsie :

Les deux axes de visée oculaire convergent au niveau du point de fixation. Les éléments de l'espace situés à la même distance de l'observateur que le point de fixation ont des images rétiniennes en correspondance d'un oeil à l'autre. Par contre, les

éléments de l'espace situés à des distances différentes donnent naissance à une disparité horizontale entre leurs images rétiniennes dont l'intensité est fonction de la distance en profondeur par rapport au point de fixation, et le sens dépendant de la localisation en avant ou en arrière du point de fixation. Les éléments en avant du point de fixation génèrent des disparités croisées tandis que les éléments en arrière génèrent des disparités directes. La disparité horizontale donne directement naissance à la sensation de distance en profondeur par rapport à l'élément de disparité nulle : le point de fixation.

L'appariement des éléments d'une rétine à l'autre ne peut s'effectuer que sur une certaine gamme de disparités horizontales qui détermine i) l'aire de fusion si l'on considère la perception résultante d'un objet unique, et ii) l'aire de stéréopsie plus étendue en considérant la possibilité de localisation en distance. Pour des disparités horizontales supérieures, les éléments ne peuvent plus être fusionnés ni localisés en avant ou en arrière du plan de référence par un traitement binoculaire et dans les conditions naturelles de mise en oeuvre du système visuel une des deux images est neutralisée pour ne plus garder qu'une information monoculaire. L'utilisation de la vision binoculaire en présentation de l'information doit nécessairement se limiter au domaine des disparités où la fusion est acquise.

L'intérêt principal de la vision binoculaire est de permettre le traitement de très faibles disparités horizontales, jusqu'à 10 secondes d'arc (soit 0,4mm à une distance de 1m). L'analyse se faisant à partir de l'interprétation d'un écart angulaire, la précision en profondeur est d'autant plus grande que le point de convergence est rapproché de l'observateur. En pratique, cela se traduit par un domaine d'efficacité de la vision binoculaire inférieur à 500m ; et même en tenant compte du poids relatif des indices binoculaires et monoculaires (Cf : interposition, perspective géométrique, parallaxe de mouvement, effet des ombres, etc...) du relief, le domaine de prépondérance de la vision binoculaire serait plus proche de la centaine de mètres (Réf.9). Toujours par relation géométrique, le pouvoir de résolution en profondeur par stéréoscopie est directement dépendant de l'écart entre les capteurs rétiniens, soit en moyenne 6,5cm.

Née de la comparaison de deux images rétiniennes, la perception stéréoscopique ne peut concerner que la zone de l'espace où les deux champs visuels monoculaires se recouvrent. En fait, les remarquables performances sont obtenues en vision centrale et l'efficacité diminue avec l'excentricité (Réf.10, 11) de telle sorte que la transition entre information binoculaire et monoculaire en champ visuel périphérique s'effectue sans gène dans la perception.

Elément du stimulus très précocement identifié par le système visuel, la disparité horizontale rétinienne est analysée en parallèle pour les différents constituants d'une image. C'est un avantage qui assure une quasi stabilité du temps de traitement indépendamment du nombre d'éléments compris dans la stimulation (Réf.12).

1.2.2- La distorsion binoculaire :

Elle provient du fait que la scène est captée par les deux yeux à partir de deux points de vue différents, le contenu des images n'est donc pas strictement identique. Cette différence de contenu s'exprime au travers de trois principales caractéristiques :

- L'image d'un objet n'a pas toujours le même contenu spectral en fréquences spatiales d'une projection rétinienne à l'autre. C'est ainsi que l'expérience princeps de BLAKEMORE (Réf.13) permet de générer une sensation de rotation en profondeur du plan résultant de la présentation aux deux yeux d'une surface plane composée de réseaux sinusoïdaux de fréquences spatiales légèrement différentes. Dans le monde réel, cette différence est d'autant plus grande que l'objet est rapproché et qu'il ne présente pas de symétrie de révolution.
- Même en l'absence de point de fixation, donc d'élément de référence à disparité nulle entre les deux rétines, les images des objets de l'espace présentent une disparité rétinienne horizontale d'autant plus grande qu'ils sont proches des capteurs. Il ne s'agit plus de disparité absolue faisant référence au point de fixation comme dans le cas de la stéréopsie, mais de disparités relatives, composantes communes des modalités binoculaires. Il faut cependant prendre en considération que le pouvoir de résolution en profondeur se dégrade avec l'éloignement en profondeur du point de fixation (Réf.11), la perception de relief émanant de cette analyse de disparité horizontale relative reste nécessairement réduite.
- Enfin, l'interposition des objets donne des faces cachées différentes entre les deux images rétiniennes ce qui est à rapprocher, sous contrainte temporelle, de la parallaxe de mouvement, élément monoculaire d'appréciation du relief particulièrement efficace.

Si la majorité des travaux sur la vision binoculaire porte sur l'analyse faite par le système visuel de la disparité rétinienne horizontale, rares sont ceux qui abordent l'influence de la distorsion binoculaire dont les caractéristiques peuvent s'avérer déterminantes dans l'exploitation d'un visuel de casque.

2- MODE D'UTILISATION DE LA BINOCULARITE DANS LES VISUELS DE CASQUE

Qu'il s'agisse de la simple amélioration des performances visuelles monoculaires par une mise en jeu bilatérale ou de propriétés spécifiquement binoculaires, il apparaît que l'état des capteurs et les conditions de prise de vue constituent un élément essentiel pour l'obtention d'un traitement de l'information de nature binoculaire. Aussi, les différentes configurations de visuels de casque sont-elles envisagées à partir des modalités de restitution des images issues de capteurs du monde environnant. Il s'agit bien là des différentes formes des stimulus soumis aux capteurs oculaires à partir desquelles l'exploitation de la binocularité est plus ou moins complète.

2.1- Visuel monoculaire

Ici le choix est fait de s'affranchir de la [illegible] du système visuel de l'opérateur dans la présentation de l'information par le visuel de casque. Si l'information symbolique éventuellement enrichie de l'image issue d'un capteur reste disponible à un oeil grâce à l'assujettissement à la position de tête, les écueils d'une stimulation visuelle unilatérale sont multiples.

La différence des deux stimulations visuelles est essentiellement caractérisée par l'asymétrie de luminance, il s'ensuit une tendance à la rivalité binoculaire mais également une perturbation de la liaison accommodation-convergence [illegible] prise de l'information (Ref.14). D'autre part [illegible] rétinien peut prétendre à l'adaptation nocturne [illegible].

Par ailleurs, ces systèmes restent dotés d'un champ de vision [illegible] de l'ordre de 40° d'où une inadaptation à l'acquisition des repères spatiaux [illegible] de la vision périphérique et une pauvre exploitation des facteurs monoculaires de la perception tridimensionnelle (3D), d'autant plus que le manque de définition des capteurs rend leur mise en oeuvre difficile et que certains d'entre eux, comme [illegible] des couleurs, sont actuellement complètement neutralisés par les dispositifs [illegible].

2.2- Visuel bi-oculaire

Dans cette configuration, les deux yeux sont stimulés et les images provenant de l'environnement sont issues d'un unique capteur. Selon [illegible] de la visualisation et l'ampleur du recouvrement des images dédiées à chacun des deux yeux, on distingue deux grands groupes :

2.2.1- Les deux yeux reçoivent la même image, le recouvrement des deux champs est complet.

Grâce à l'identité théorique du stimulus, tout risque de rivalité oculaire est éliminé et la commande de la triade pupille-accommodation-vergence a des afférences concordantes en provenance des deux yeux. En fait, le recouvrement complet des champs visuels monoculaires introduit des disparités horizontales et verticales d'autant plus importantes qu'il s'agit d'une zone périphérique : ces disparités sont liées aux systèmes optiques utilisés et altèrent le bénéfice de l'identité de l'image d'origine. En tout état de cause, l'apport est limité au renforcement des informations monoculaires par la mise en jeu bilatérale. Il n'existe aucun gain sur le plan de l'étendue du champ de vision et aucune sollicitation spécifique de la vision binoculaire. Notamment, seuls les indices monoculaires de la perception tridimensionnelle restent opérants. Cela est obtenu au prix d'un dispositif plus lourd -avec les conséquences qui en découlent sur la mobilité de la tête- qui a perdu toute sécurité vis-à-vis de la panne du capteur associé.

2.2.2- Les deux yeux reçoivent 2 sous-images, le recouvrement des champs est partiel.

Ce cas est obtenu si l'image provenant de l'environnement est issue d'un unique capteur puis scindée en deux sous-images dont le contenu n'est identique que dans la portion centrale du champ de vision. Les zones périphériques de l'image captée sont adressées de façon monoculaire, que l'attribution soit homolatérale ou controlatérale selon les dispositifs. Le principal avantage est le gain en champ de vision de l'ordre de 50% en ayant la possibilité de garder la même résolution de l'image et en améliorant la mise en oeuvre des facteurs monoculaires de l'évaluation 3D (Réf.15). Il n'en reste pas moins que les inconvénients liés à l'unicité du capteur sont reconduits dans le domaine de la sécurité comme dans celui de la mise en oeuvre de la binocularité. Enfin, trait commun à tous les dispositifs à recouvrement partiel, les zones latérales monoculaires engendrent une rivalité oculaire paracentrale et une instabilité oculomotrice. Ce phénomène est mieux connu sous le terme de luning.

2.3- Visuel binoculaire

Deux capteurs sont mis en oeuvre, ils délivrent chacun une image dédiée à un oeil. Une nouvelle subdivision de cette catégorie de visuels est à prendre en compte au vu des diverses composantes de la vision binoculaire.

2.3.1- Les images proviennent de capteurs dont les axes de prise de vue sont parallèles.

La redondance des capteurs assure la sécurité de la source image tout en conservant éventuellement un large champ de vision. Cette solution est en outre dotée d'une certaine facilité de mise en oeuvre puisque la position de l'axe de prise de vue est fixe et prédéterminée.

Cependant, l'analogie avec la vision binoculaire en conditions normales se limite à l'existence de 2 points de vue différents de la scène. Il n'existe pas de plan de référence puisque les axes sont parallèles, pas d'élément de disparité nulle entre les deux images permettant l'interprétation de disparités rétiniennes absolues, d'où exploitation des informations binoculaires limitée à la distorsion binoculaire. On ne peut qualifier ces dispositifs de stéréoscopiques puisqu'il ne sollicitent que partiellement la binocularité et notamment pas la stéréopsie.

2.3.2- Les images proviennent de capteurs dont les axes de prise de vue convergent en un point de l'espace

Ce dispositif rassemble l'ensemble des conditions nécessaires à l'exploitation de la totalité des possibilités d'analyse de la vision binoculaire. En effet, l'interprétation des facteurs binoculaires peut se faire compte-tenu de l'élément de

disparité nulle entre les deux images : le point de convergence des axes de visée des capteurs. La perception tridimensionnelle de l'environnement s'élabore à partir de ce repère spatial par une localisation en avant ou en arrière selon la disparité horizontale entre les deux images. On constate en effet que les deux modalités de disparités horizontales sont restituées tandis qu'un système à capteurs parallèles n'est susceptible de générer que des disparités relatives de type croisé.

Cela étant, le choix du lieu de convergence des axes de visée des capteurs apparaît déterminant pour une représentation 3D appropriée. S'il est fait en faveur d'une distance fixe, il s'agit d'un compromis a priori tenant compte des données sur la tâche principale de pilotage ; si l'option est prise de l'assujettir à la position du regard du pilote, les conditions sont optimales pour l'utilisation de la binocularité mais cela sous-entend un détecteur de la position des yeux en plus du détecteur de la position de la tête.

L'exploitation attendue de la stéréopsie est conditionnée par la superposition des champs de vision monoculaires. Pour éviter la transition en vision centrale d'une restitution stéréoscopique à une restitution monoculaire -ce qui est contraire aux conditions habituelles de mise en oeuvre du système visuel- un recouvrement total des champs de vision est préconisé.

3- PROBLEMES LIES A L'UTILISATION DE LA BINOCULARITE

Les différentes conditions de visuels bi-oculaires ou binoculaires recouvrent de nombreux modes de sollicitation de la vision binoculaire dont aucun n'a vraiment de correspondance avec la mise en jeu en conditions habituelles. Selon la perturbation dans la chaine d'acquisition des données visuelles peuvent naître des problèmes de traitement visuel qui diffèrent en fonction du profit attendu d'un visuel dédié aux deux yeux.

3.1- Si le but est uniquement de ne pas être gêné par une stimulation strictement monoculaire, on se limite à l'apport de la binocularité dans l'amélioration des grandes fonctions visuelles. Il faut alors disposer d'images aussi peu différentes que possible l'une de l'autre pour faciliter leur fusion et éviter l'interprétation d'éventuelles différences en terme de perception 3D. Dans ces conditions, le problème est essentiellement circonscrit à la restitution de l'image. Des travaux ont déjà été entrepris dans ce domaine. Quelques exemples en sont donnés.

3.1.1- En laboratoire : étude de la tolérance aux disparités de distorsion dans la restitution de l'image

Ces disparités sont inévitables et directement dépendantes des systèmes optiques, l'identité absolue entre les systèmes dédiés aux deux yeux n'étant pas technologiquement réalisable. En conséquence, l'intensité des disparités parasites est d'autant plus grande que le champ de vision est plus étendu. Elles ont pour origine potentielle : un manque d'alignement des deux dispositifs de projection, un grossissement différent, une rotation relative par rapport au centre d'une image (Réf.16). Si les répercussions de ces distorsions de l'image concernent aussi bien les dispositifs bi-oculaires que binoculaires, les limites de tolérance ne peuvent être établies qu'en référence à des images d'origine identiques pour éviter toute interférence entre distorsion "binoculaire" et distorsion dans la restitution de l'image.

A partir de ses travaux et d'une revue de la littérature, SELF (Réf.17) a défini ces limites tenant compte de critères de confort, de l'effet cumulatif de l'inconfort au cours de la visualisation prolongée et de la variabilité interindividuelle. C'est ainsi que l'on peut admettre jusqu'à 3,4 minutes d'arc de disparité verticale ou horizontale divergente et 8,6 minutes d'arc de disparité convergente. Les limites de rotation et de grossissement sont directement déduites de ces tolérances verticales et horizontales qu'elles engendrent et dont l'intensité dépend du champ de vision. A noter que la perception stéréoscopique n'est pas sensiblement affectée par une disparité verticale inférieure à 25 minutes (Réf.18) donc bien au delà des limites de tolérances aux disparités de restitution de l'image.

3.1.2- En pratique : étude de la rivalité oculaire dans l'utilisation de visuels de casque

L'intérêt d'une stimulation des deux capteurs visuels pour tirer profit de la redondance des afférences, sans même avoir recours aux caractéristiques spécifiquement binoculaires est mis en évidence dans une expérimentation effectuée sur avions d'armes (Réf.19). Les pilotes ont effectué des vols sur F16 équipés soit de visuels de casques monoculaires soit de visuels bi-oculaires dont les deux images étaient semblables. Bien qu'on retrouve une très grande susceptibilité individuelle, la grande majorité des pilotes rapporte une plus grande facilité d'exécution de leur tâche de pilotage avec le dispositif bi-oculaire, la prise d'information étant perçue comme plus naturelle et moins sujette à fluctuation.

Cette étude subjective peut être étayée de données objectives par des mesures quantifiées de la triade pupille-accommodation-vergence effectuées lors de l'utilisation de visuels monoculaires ou bi-oculaires par MOFFITT (Réf.14). Un équilibre en accord avec la distance de collimation est observé en stimulation bi-oculaire tandis qu'il existe une déviation en vergence de l'oeil non stimulé en configuration de visuel monoculaire. Cette déviation est conditionnée par la position de dark-vergence mesurée par ailleurs pour le sujet. Elle a pour conséquence une tendance à la convergence de l'oeil stimulé et un niveau d'accommodation correspondant ; il s'ensuit un décentrage de l'oeil par rapport à l'image et une perte de netteté de l'image particulièrement perceptible avec la symbologie et majorée par l'occultation de l'oeil libre parfois réalisée par l'opérateur pour se concentrer sur l'information monoculaire.

Dans de moindres proportions, la rivalité oculaire est encore un problème dans les dispositifs dont le recouvrement des deux champs de vision n'est que partiel. Le luning peut être restreint par divers artifices tels l'estompage progressif de l'image dans sa portion marginale binoculaire, l'insertion d'une zone dépourvue d'information sur la zone correspondante sur l'autre oeil ou encore l'attribution croisée des champs latéraux monoculaires (Réf.15).

Dans ce type d'utilisation de la binocularité, la duplication des capteurs est plutôt une gène qui majore les différences entre les deux images. L'avantage est limité à l'augmentation potentielle du champ de vision.

3.2- Si le but est d'exploiter la spécificité binoculaire, les différences entre les deux images prennent toute leur valeur pour la perception 3D. Le problème est alors de résoudre le hiatus entre vision binoculaire dans des conditions physiologiques et vision binoculaire avec interposition d'un système optique. L'analyse concerne tout à la fois le niveau de la prise de vue et celui de la restitution des images.

Pour l'ensemble des visuels binoculaires, l'effet "binoculaire" peut être exacerbé, i.e. les différences entre les deux images monoculaires majorées, en écartant les capteurs. En créant ces conditions d'"hyper-relief", le domaine d'efficacité de la vision binoculaire n'est plus limité aux quelques centaines de mètres habituels mais est adapté à l'échelle des grandeurs aéronautiques.

3.2.1- Que peut-on tirer de l'exploitation exclusive de la distorsion?

Les connaissance actuelles ne permettent pas de prédire le bénéfice sur la perception 3D que l'on peut attendre de dispositifs où la distorsion binoculaire est le seul élément différentiel d'une image à l'autre. Si l'option devait être définitivement faite d'un visuel de casque à double prises de vue parallèles, ces études devraient être menées et détermineraient l'apport attendu dans la représentation tridimensionnelle de l'espace.

3.2.2- Si les axes de visée des capteurs convergent en un point de l'espace, il faut que les disparités entre les images soient suffisantes pour avoir une signification pour le traitement binoculaire.

C'est typiquement le cas d'un écart entre les capteurs supérieur à l'écart inter-pupillaire. Les différences entre les images sont ainsi plus grandes mais elles doivent rester tolérables pour une fusion perceptive par l'opérateur. Il apparaît alors nécessaire de déterminer les composantes de l'image qui conditionnent la mise en oeuvre adaptée de la binocularité. Les conséquences en sont immédiates quel que soit le type d'image utilisé dans la visualisation. Pour des images de simulation ou pour la symbologie, elles conditionnent la synthèse des stimulations visuelles ; pour des images issues du monde réel par l'intermédiaire de capteurs, elles vérifient la présence des éléments efficaces à la binocularité dans la stimulation ou orientent les développements technologiques pour qu'ils y soient introduits.

Une étude menée avec des stimulations de synthèse au contenu en fréquences spatiales très sélectif a ainsi mis en évidence la dépendance des capacités de fusion binoculaire au contenu fréquentiel spatial de stimulations stéréoscopiques (Réf.20) Lors de la présentation d'une disparité horizontale donnée entre les stimulations haploscopiques, la fusion peut s'exercer selon deux modalités : la première ne met en jeu que des processus neuronaux et assure une fusion d'emblée pour une gamme relativement limitée de disparités ; la seconde intervient pour des disparités supérieures jusqu'à ce que soit atteint le seuil de fusion maximale, elle fait intervenir des mouvements de vergence réflexes (convergence ou divergence selon le type de disparité) et requiert d'autant plus de temps pour accéder à la fusion que la disparité en cause est importante. Les deux composantes de la fusion binoculaire s'exercent sur de plus grandes étendues de disparités horizontales lorsque la stimulation est constituée de basses fréquences spatiales. La présence simultanée dans la stimulation de fréquences spatiales associées à des domaines de fusion très différents permet de se rapprocher des capacités de fusion autorisées par la fréquence la plus basse qu'il s'agisse de la fusion neuronale ou de la mise en jeu de l'oculomotricité réflexe. Ce dernier résultat est intéressant pour la fusion des images véhiculant de l'information qui sont toujours des stimulations visuelles à contenu fréquentiel complexe. La gamme des disparités disponibles dans des visualisations stéréoscopiques dont la fusion binoculaire est impérative, n'est pas réduite à celle associée aux hautes fréquences spatiales ; les basses fréquences constituent l'élément déterminant pour la sollicitation optimale des capacités de fusion binoculaire.

La variabilité inter-individuelle dans le traitement des stimulations dédiées aux deux yeux existe à tous les niveaux ce qui pose en conséquence le problème de l'aptitude à l'utilisation de ces divers visuels de casque. Les méthodes d'évaluation des caractéristiques binoculaires des personnels navigants ne semblent pas pouvoir constituer un élément de réponse. En effet, elles vérifient l'existence d'un sens stéréoscopique, déterminent la position anatomique résultant de l'équilibre oculomoteur et la résistance de la fusion à une contrainte en disparité exercée de façon croissante. Il n'est en aucun endroit pris en compte les caractéristiques psycho-physiques des stimulations employées qui cependant influent sur les capacités de traitement de la vision binoculaire comme c'est le cas pour la composition en fréquences spatiales. La fusion n'est pas non plus évaluée sur un mode actif par la détermination de l'étendue des disparités horizontales qui peuvent donner lieu à une fusion sensorielle lors de leur présentation haploscopique. De nouveaux tests de la vision binoculaire devraient

être développés et mis en oeuvre qui prennent en compte ces paramètres et assurent une évaluation fonctionnelle des capacités binoculaires (Réf.21).

L'intérêt en a déjà été montré par la détermination des capacités de fusion de sujets modérément hétéropnoriques pour des stimulations au contenu fréquentiel variable. Il en résulte une catégorisation des sujets non plus sur leur degré d'hétérophorie mais sur leurs capacités d'utilisation de leur vision binoculaire donnant lieu à un domaine de fusion comparable ou non à celui d'une population de référence (Réf.22).

3.2.3- Le bénéfice de la binocularité peut-il être maintenu indépendamment de la localisation du point de convergence des capteurs en concordance avec le point de fixation? C'est à dire peut-on s'affranchir de l'adaptation en continu de la fonction accommodation-vergence?

En ce qui concerne l'accommodation, il ne devrait pas y avoir de problème car les distances aéronautiques sont de grande dimension. Dans ce domaine de l'espace l'accommodation varie peu. Ceci est congruent avec les profondeurs de champs des systèmes optiques également de grande dimension.

Le problème de la convergence des axes de visée est tout autre puisqu'il conditionne directement la valeur de la disparité horizontale absolue créée par le système de prise de vue. Cette question non résolue est déterminante pour l'utilisation de visuels complètement binoculaires.

3.2.4- L'interprétation des disparités résiste-t-elle au bruit aéronautique?

Lorsque l'information est obtenue à partir d'un capteur, celui-ci est soumis à des contraintes données de l'environnement. Les effets qui en découlent pour l'image sont transmis identiques aux deux restitutions d'un dispositif bi-oculaire. En prenant l'exemple d'une vibration appliquée au capteur, la fusion binoculaire s'effectue sur des stimulations ayant la même fréquence de vibration, sur la même amplitude, toujours en phase. Les données obtenues sur la tolérance aux disparités de distorsion dans la restitution de l'image sont transposables.

Quand les capteurs sont dupliqués, les contraintes locales peuvent varier de l'un à l'autre. Le traitement binoculaire doit continuer d'extraire l'information de relief en neutralisant le bruit majoré du signal visuel. En conservant l'exemple de la vibration des capteurs, quelle tolérance a-t-on lorsque la fréquence de vibration, l'amplitude diffèrent, avec ou sans déphasage d'un oeil à l'autre? De nouvelles données expérimentales sont ici nécessaires pour déterminer la capacité de traitement binoculaire en fonction de ces fluctuations dynamiques des stimulations appariées.

3.2.5- Pondération entre les facteurs monoculaires et binoculaires.

La sensation résultant du traitement de l'information binoculaire est une perception de distance relative par rapport au point de convergence des capteurs. Elle se développe chez l'homme par l'interprétation des disparités horizontales liées à l'écartement physiologique des capteurs oculaires. Le bénéfice que l'on peut attendre d'une présentation stéréoscopique de l'information issue du monde réel est fortement dépendante des données quantitatives en distance que l'on peut extraire de la disparité horizontale produite. La transition d'une perception de profondeur dans des conditions de prise de vue modifiées sous-entend une forte interaction entre facteurs monoculaires 3D et binocularité pour l'interprétation générale des formes en relief et l'estimation de la distance absolue du point de fixation.
Des résultats expérimentaux manquent concernant la perception des distances à partir de dispositifs binoculaires exacerbant les disparités horizontales.

4- SYNTHESE ET PROPOSITIONS

4.1- Visuel de casque et tâche de pilotage.

Les objectifs attendus des visuels doivent être clairement définis en fonction de la tâche.

Dans le cadre de la restitution d'imagerie issue du monde réel, l'exploitation maximale de la binocularité n'est obtenue que par les visuels binoculaires convergents à recouvrement complet de champs de vision monoculaires. Le corollaire en est une perte en champ total d'où une diminution des indices monoculaires 3D et des éléments les plus périphériques utiles à l'orientation spatiale. En contre partie, il existe un gain en résolution en distance. En attendant que les dispositifs de visuels de casque soient plus complètement adaptés aux données de la physiologie visuelle pour permettre l'utilisation des propriétés de la vision centrale et de la vision périphérique, un choix est à opérer dans cette alternative. Il repose exclusivement sur la tâche principale du pilote pour la priorité que l'on donne aux éléments de l'information. Faut-il neutraliser l'information binoculaire sur la perception des distances et privilégier l'extension latérale des champs de vision pour favoriser l'interprétation des éléments périphériques? Ou l'inverse?

4.2- Cas de la simulation.

La simulation offre un contexte particulier pour un visuel de casque binoculaire. On s'affranchit de tous les problèmes de contrôle des capteurs et des fluctuations dans leur mise en oeuvre. On améliore la représentation de l'espace simulé. Un exemple de l'intérêt de la stéréoscopie est donné par l'évaluation des distances et la réalisation d'une tâche de pilotage prenant en compte la perception 3D de l'environnement dans le cadre d'une simulation de ravitaillement en vol (Réf.23). Une comparaison des données résultant de moyens de visualisations monoculaires, bi-oculaires et binoculaires ne montre pas de différence pour l'estimation de la distance au cours de phases de

ravitaillement en vol automatique. Par contre, lors de l'exécution de la tâche de pilotage, la performance est significativement améliorée en visualisation stéréoscopique, la jonction avec le panier de ravitaillement se faisant à la distance appropriée, tandis qu'en visualisation monoculaire ou bi-oculaire on assiste systématiquement à un rapprochement abusif du ravitailleur. A noter que cette amélioration objective de la performance n'est pas ressentie par les pilotes qui rapportent une relative inhabileté due au changement imposé dans leur procédure habituelle de ravitaillement. Si la perception des distances est améliorée, le contrôle de l'horizontalité de l'avion est altéré ce qui est à rapporter à la restriction de champ attachée aux dispositifs stéréoscopiques.

4.3- Cas de la symbologie.

Outre l'utilisation des caractéristiques de la vision binoculaire pour la perception du monde extérieur, l'introduction d'une disparité horizontale entre les composants homologues de la symbologie dédiés à chaque oeil offre un nouvel élément de codage de l'information, et ce dès qu'il existe une zone de recouvrement des champs de vision monoculaires aussi réduite soit-elle. Le traitement en parallèle de la disparité horizontale favorise le délai de la prise d'information et la sélection d'un paramètre de la symbologie. Ce type de codage est donc particulièrement adapté aux situations d'alerte dans l'interface homme-système. Il ne reste qu'à tenir compte des caractéristiques psycho-physique du stimulus sélectionné pour l'adaptation de la disparité horizontale aux capacités de fusion à respecter.

CONCLUSION

La vision binoculaire constitue un élément directement disponible de la perception de l'environnement pour contribuer à l'élaboration de la représentation tridimensionnelle interne de la situation. Le couplage du visuel de casque à la position de la tête le fait apparaître comme support privilégié pour la mise en oeuvre de ces capacités binoculaires dans le cadre aéronautique où la représentation de l'environnement a d'autant plus d'importance que la réaction du pilote doit être adaptée dans chaque dimension avec une contrainte temporelle maximale.

Si les propriétés de la vision binoculaire ne devaient pas être utilisées dans un futur visuel, mieux vaudrait ne pas multiplier les problèmes d'interface homme-visualisation en dupliquant les capteurs, mais au contraire lutter au mieux contre les disparités parasites entre les images dédiées à chacun des deux yeux pour éviter quelles ne donnent lieu à interprétation en termes d'information binoculaire. A l'inverse, pour espérer disposer des avantages potentiels d'un visuel binoculaire, l'ensemble des propriétés d'analyse de la binocularité doit pouvoir s'exprimer. Cela sous-entend l'élaboration d'un visuel "totalement" binoculaire où la convergence des axes de visée des capteurs est un élément essentiel. Ses limites d'utilisation sont fournies par la capacité de transposition de la chaîne d'acquisition des données visuelles pour la conservation d'un traitement de l'information stéréoscopique. En tout état de cause, l'équivalence entre visuel de casque binoculaire et deux yeux stimulés par deux sources images ne peut être établie aussi facilement.

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DESIGN OF HELICOPTER NIGHT PILOTAGE SENSORS: LESSONS LEARNED FROM RECENT FLIGHT EXPERIMENTS AND FIELD ASSESSMENTS

by

Richard Vollmerhausen
Trang Bui
Carolyn Nash
US Army CECOM Center for Night Vision and Electro-Optics
Fort Belvoir, VA 22060-5677, USA

ABSTRACT

The Army requirement to fly helicopters at low level at night led to the development and fielding of night vision pilotage sensors. These sensors have included image intensifiers (I^2) operating in the near infrared as well as 8 to 12 micron thermal imagers. The design of current pilotage sensors was driven by available technology. There were no clear data for optimum pilotage sensor design, to enable the designer to trade off sensor field of view (FOV) and resolution or to predict the performance increase which could be obtained by increasing sensitivity. The Center for Night Vision and Electro-Optics (CCNVEO) is establishing design criteria for night pilotage sensors. Our program includes flight experiments to define sensor characteristics which optimize flight tasks as well as assessments of the performance of fielded systems. We conclude that terrain flight can be accomplished with reasonable pilot workload using a head-tracked sensor with 40 degree FOV and 0.6 cycles per milliradian (cy/mrad) resolution. Larger FOV or better resolution will lessen workload and improve confidence; however, the ability to resolve scene detail of 0.6 cy/mrad is essential and should not be traded for increased FOV. Further, a pilotage system which provides both thermal and I^2 imagery will significantly enhance system capability to support a variety of flight tasks under a wide range of environments. We also conclude that solid state cameras with detector dwell time equal to the standard video field rate are not suitable for use in helicopter pilotage systems. The long dwell time leads to image blur due to the head and scene motion associated with many pilotage tasks.

Helmet Mounted Displays: Human Factors and Fidelity

Peter L.N. Naish and Helen J. Dudfield

Human Factors Division,
Flight Systems Department,
The Royal Aerospace Establishment,
Farnborough, Hants. U.K.

Helmet mounted display (HMD) systems, of the kind able to present what has been termed virtual reality, will not be able to present a completely faithful rendering of the world. This paper shows how non-HMD technology may be used to assess the effects of this deficiency. Three aspects of the helmet mounted system are considered, and experiments are reported, which were designed to determine the degree of reality required in flyable equipment. The areas covered are time lag in the display, the need for colour and the use of 3-D sound. It is concluded that, for the parameters considered, currently available technology is able to produce stimuli which are adequate for the anticipated use of HMDs.

INTRODUCTION

There is an increasing acceptance that pilots in the future will receive at least some of their necessary flight information via helmet mounted displays (HMDs). Over and above the obvious physical problems which will have to be addressed, such as the effects of increased mass and the placing of the centre of gravity, there will inevitably be the more cognitive human factors issues to resolve. There would be no such problems (or at least, no more than at present), if the helmet display could be made to present the pilot with a view identical to that which is received in a current cockpit. However, it is clear that flyable systems will not in the foreseeable future be able to generate outside world views with such fidelity. The display of flight data presents less of a problem, in the sense that it would not be difficult to present a virtual version of the current cockpit instrumentation. However, given the flexibility which the virtual world will offer, it would be worth considering novel designs of display, which may prove to be better than current systems. In order to explore these matters further, the Human Factors Group of the Royal Aerospace Establishment has commissioned the development of high performance HMD system, to be built by an industrial consortium. The system will comprise both the helmet mounted optics, and the hardware and software to drive the displays. It is hoped that this package will make it possible to address the kinds of issues raised above, but in the mean time some of the more crucial questions may be answered, at least in part, without recourse to the helmet mounted equipment; experiments with less exotic apparatus may be used. Three such studies will be reported here.

SYSTEM LAG

Discussions with pilots make it clear that they are disinclined to fly, as they describe it, "with their heads in a bucket"! They wish to see the outside world. As the use of HMDs becomes more widespread, then a full acceptance of the virtual world may evolve, but for the present, most pilots are prepared only to use some of the HMD benefits all of the time and all of the benefits some of the time. The potential advantage of being insulated from the outside is definitely one for occasional use! However, it is deemed entirely acceptable that the outside view be enhanced, by accenting features of importance. This facility will require that the helmet contains a beam-splitting feature, to permit simultaneous viewing of the projected image and the real world scene. From a terrain data base it will then be possible to predict the locations of features in the flight path and so, for example, to highlight obstacles such as power lines and chimneys. Such obstructions might also be detected by means of active sensors, with the information being fused with that of the data base (1). The HMD would generate a stylised symbol of the obstacle, with which to overlay the real world structure. The benefits of such an alerting system in poor visibility, low level flight are obvious.

An essential requirement of an obstacle cueing system is that the cues are displayed in the correct place. It will not be difficult to determine the exact location of the aircraft and hence select the appropriate portion of the data base. However, to determine precisely where to draw the symbology in the HMD, taking account of the aircraft attitude and pilot's head position, will require some considerable computational power. Inevitably, the calculations involved will take time. This, in turn, will give rise to a lag in the system. Such a delay would not prove a problem in straight and level flight, for it could be allowed for in the computations. However, system lag may prove troublesome during rapid manoeuvres. The difficulty is not simply that the warning symbols may no longer be precisely co-located with the cued objects; the delayed response of the system will also give erroneous feedback on aircraft attitude. Consider, for example, the situation where the pilot initiates a rapid roll. If the obstacle cues are not

redrawn sufficiently quickly, they will roll with the 'plane. If the cues are salient (and they should be, if they are to serve their warning function) then they will tend to override the real world information, and suggest to the pilot that no roll has as yet taken place. It is clear that a significant system lag would be potentially dangerous and consequently unacceptable. An experiment was conducted to determine the maximum permissible lag for such a system. It formed part of a series of experiments, addressing the issue of obstacle cueing more widely (2).

Apparatus

A wooden static cockpit mock-up was used, built around a Tornado ejection seat, with Tornado stick and throttle. These controls were linked, via potentiometers and A-to-D converters, to a pc computer. This controlled a flight model, and was in turn linked via ethernet with an Iris workstation, which dealt with image generation. The images were displayed by projection from a Barco video projector, directed at a screen on the wall in front of the cockpit. The background view was derived from a terrain data base, drawn as a patchwork of 200m squares, with sun angle shading. This, and all other components of the display, was presented in monochrome green. Superimposed upon the "outside world", a head-up display was also projected. Thus, the HUD was not a physical entity, but the symbology, which was in the standard RAF fast-jet format, was projected to subtend the normal angle from the pilot's position. Also combined with the data base were a series of obstructions, such as power lines, pylons and cooling towers, which were computer generated graphics, located in the terrain by the experimenter, in advance of the experiment. Finally, a set of stylised obstacle symbols was available, and the appropriate cue could be superimposed upon an obstacle, as it appeared in the flight path.

Subjects

The experimental subjects were eight test pilots, experienced with fast jets, familiar with the concept of obstacle cueing, and with some experience of FLIR, on head-up and head-down displays.

Method

A predefined course was set up in the data base, with obstacles placed along its length. The course was defined by a series of waypoints, each being represented on the display by a large X, as the pilot came within visual range. They thus appeared to be superimposed upon the scene, just as the obstacle cues were. Pilots acquired the correct heading between waypoints by means of a track index, an upward pointing arrowhead, just below the heading tape at the top of the HUD. Pilots were instructed to follow the course at a speed of approximately 350 knts and to maintain a height of 200 ft. Departures from this height were recorded as root mean square (rms) error. Additionally, each subject completed a detailed questionnaire, highlighting difficulties and advantages of the obstacle cueing system.

Lag was introduced into the obstacle cueing, in increments of one frame, to a maximum of five frames. The display frame rate was approximately 7 Hz, so lags were between zero and 700 ms, in steps of 140 ms. For half the flying time, the pilot was forced to continue the mission as best he could, under the five experimenter-imposed lag times. During the remainder of the trial, the pilot had the option of cancelling the lag. It increased during this period in steps of one frame, at the rate of one step per 80 frames. At any point, the pilot could press a stick-mounted switch, to reset the lag to zero. The lag magnitude at which the pilot reset was monitored.

Results

The mean point of lag resetting lay between 2 and 3 frames. This result corresponded well with pilots' subjective reports of the level at which they found lag to be damaging to their performance. The finding suggests that lags should be kept below 300 ms. However, an examination of the flight data (Figure 1) suggested that even more stringent timing will be required. An analysis of variance on the error scores, under the six levels of lag (0 - 5 frames) revealed a highly significant effect ($p<0.001$). Individual comparisons, by the Neuman-Keuls test, showed that even the lowest lag duration (140 ms) produced significantly ($p<0.05$) worse performance than in the no-lag condition.

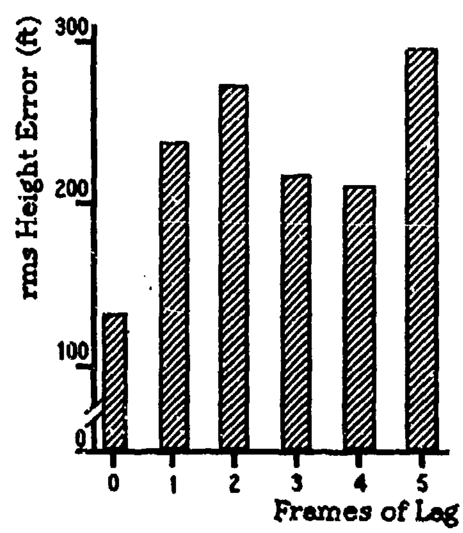

Figure 1 Lag-induced height errors.

Conclusion

With the non-HMD technology described it has obviously been possible to gain some indication of the level of lag which will be tolerable in a helmet mounted system, although it was not possible with the equipment available to determine the precise magnitude at which lag has a measurable effect upon flight performance. It is interesting to note that small degrees of lag would not be detrimental in a completely enclosed HMD. It is the separation of synthetic image from real counterpart which causes the difficulty. If all the scene were synthetic, the difficulty would be resolved.

THE USE OF COLOUR

The real world is, of course, coloured and in attempts to represent it there is a natural inclination to use a polychrome display. However, to incorporate colour in a HMD will almost certainly exact penalties in cost, weight and complexity. Many designers would breath a sigh of relief, if it could be shown that the use of colour was not essential to good flying! The Animal Kingdom offers conflicting clues on the matter. Disquietingly for the designers, the birds, the natural fliers, do have colour vision. However, this seems in large part to be linked to their coloured plumage and its use in activities such as courtship rituals. Most of the mammals, including the high-speed hunters like the Big Cats, survive very well in a monochrome world. For a HMD, a compromise position may be possible, using a two-colour system, such as is provided by the Penetron crt. Although the outside world could not be painted with great fidelity, at least primary flight data could be given additional saliency, by suitable choices of colour. If the HMD were being used principally in the transparent mode, then there would not in any case be a need for producing a coloured outside view.

It was decided to make a comparison of the effectiveness of monochrome, bi-chrome and full-colour HUD symbology and to introduce factors which might plausibly be expected to modulate any beneficial effects of redundant colour coding. Thus, workload would be increased, since it might be expected that the putative advantages of colour may only become apparent, when the overall task difficulty is high. The second factor to be manipulated would be subject experience. Although a highly practised subject, entirely familiar with a monochrome HUD, may not show any performance improvement on the introduction of colour, the same may not be true for a naive subject. If the colour were being used redundantly, then the additional information might be expected to facilitate the acquisition of the flying skill.

Apparatus

The equipment used was identical to that described above, with the addition of a voice recognition system, which was used in a secondary task, designed to increase workload. The background scene remained in monochrome green, as was the HUD symbology in the monochrome condition. However, for the Penetron simulation red and amber were introduced, permitting the use of three colours, red, green and amber, on the HUD. For the full-colour condition, those three colours were augmented with brown and blue.

Subjects

Eighteen subjects were tested, half being experienced civil pilots and simulator personnel, and the remainder non-flying personnel from the RAE and RAF Institute of Aviation Medicine. The intention was to compare the performances of these two populations, to determine whether colour displays were more advantageous to the inexperienced.

Method

Subjects were required to fly a pre-marked course, as described in the earlier experiment. They were asked to keep within a stringent flight profile, with a speed of 400 knts, height of 250 ft and, as far as possible, with wings level. Departures from these parameters were recorded. Subjective ratings were also taken from the pilots at the end of each flight. For this, the NASA Task Load Index (TLX) was used. In the colour conditions, which were presented in balanced order across subjects, the appropriate HUD symbols changed colour, to warn of discrepancies from the desired profile. Thus, the altimeter display changed from green, first to amber, then to red, if the height moved too far from the desired value. Amber was used when the error reached ±50 ft, then red at ±100 ft. Similarly, colour changes occurred for errors in speed, course and attitude. This green/amber/red colour coding was used in both the Penetron and full-colour conditions, but in the latter the upper pitch bars were coloured blue and the lower brown.

The maintenance of the flight profile was the primary task. As a secondary activity, pilots were required from time to time to make direct voice inputs (DVI) from their head-worn microphone. At random intervals a three-digit string was presented, in a box, just below the lowest pitch bars of the HUD. These digits were to be spoken into the microphone and were interpreted by the voice recognition system. The latter then initiated a direct voice output (DVO), repeating the digits which it had "heard". These were presented to the pilot, over headphones. If the pilot decided, from the DVO, that the string had been correctly recognised, then he or she pressed an accept button on the stick. If there had been an error, the DVI had to be repeated. Training on the speech recogniser was carried out, before the experiment proper.

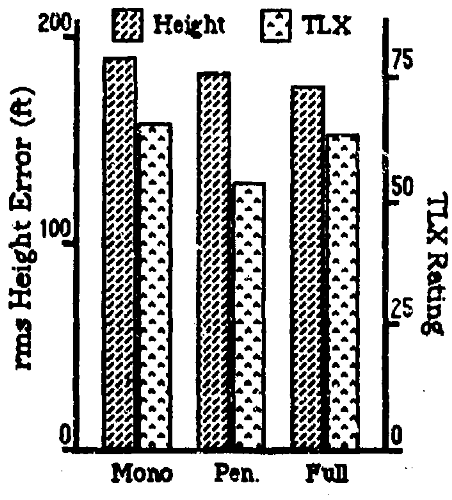

Figure 2 Height errors and TLX ratings for Monochrome, Penetron and Full Colour HUDs.

Results

The ability of pilots to maintain the required height proved a sensitive measure, and was used to assess the utility of colour coding. It showed that inexperienced subjects performed worse than pilots ($p<0.001$) and that, for all subjects, the addition of DVI was detrimental to the primary task ($p<0.001$). There was a significant ($p<0.05$) interaction between the subjects' experience and performance under DVI, with the experts suffering less with the secondary task. However, the presence or absence of the redundant colour information had no significant effect upon performance (Figure 2). In contrast, subjects reported a preference for the colour HUDs, particularly the Penetron version. The TLX scores, also shown in Figure 2, mirrored these preferences, with the subjective workload in the Penetron condition being significantly lower than both the full-colour and monochrome conditions ($p<0.05$).

Conclusions

Clearly more research will be required, to elucidate these conflicting results, and perhaps it should await delivery of a HMD. At this stage it would seem that, by objective measure, a monochrome display may be adequate. However, it would be preferable if possible, to provide a system which was not only adequate, but subjectively "better" from the pilot's point of view. Moreover, the use of colour coding may have been sub-optimal in this study and other, more effective roles for colour may be identified in the future. Nevertheless, if the addition of colour is for the time being impracticable, then it would seem that the introduction of HMDs need not be delayed, for fear of a performance decrement.

3-D SOUND

HMDs will, of course, require head tracking systems, so that the appropriate scene may be generated in front of the wearer's eyes. The presence of the head tracker makes it relatively simple to introduce directional sound into the system. Such 3-D sounds could alert the listener to the direction of a threat, or improve situational awareness, by making a wingman's voice seem to come from the appropriate direction. Head tracking is required for this implementation, since apparent external sound sources will have to appear fixed, as the pilot turns his head. Indeed, the ability to turn the head, and in a sense "triangulate" the sound source, may prove to be an important part of establishing convincing localisation of the sounds.

In comparison with the computational power required to generate moving stereo visual images for a HMD, the signal processing needed for stereo sound is rather trivial - or at least, most of it is! When a sound is required to be perceived as coming from one side, then its arrival at one ear will be delayed with respect to the other. This is easily achieved with a digital "bucket-brigade" delay line, of variable length, to suit different apparent sound directions. The sounds at the two ears will also need to differ somewhat in spectral composition, since the head acts as a low-pass filter. Consequently, higher frequency components are relatively attenuated, in the ear distal to the sound source. Although somewhat more complex than the delay system, digital filtering is not difficult to implement. It has often been stated (e.g. 3) that these two kinds of cue alone will be insufficient to produce a convincing sensation of directionality in synthetic stereo sounds. The missing component is the effect of the pinnae - the outer ear flaps - which also modify the spectral composition of the sound. The complex interactions between the folds of the pinna and sounds from different directions are not amenable to simple calculation. There is a solution to this problem, although one which demands a good deal of real-time calculations to implement. It entails generating a look-up table of filter parameters, to represent head-plus-ear performance, over the whole range of possible sound directions. Not only does the use of the table require many fast computations, but it also has to be prepared in advance. Ideally, a separate table is needed for each listener, since we do not all have the same shaped ears. The RAE Human Factors Group has not asked for this latter sophistication in the commissioned HMD, and an experiment has been conducted to determine the effectiveness of a more basic system.

Apparatus

Much of the equipment used has been described before (4). It was built around a Macintosh computer, which controlled the experiment and presented an on-screen tracking task, controlled by the mouse. The subject sat in front of the computer, below a horizontal hoop, which carried eight equally spaced light emitting diodes (LEDs). The subject wore headphones, through which warning sounds could be played. They were prerecorded on tape, and intended to warn of the illumination of a LED. In addition to these components, used during the experiment, a dummy head was employed during the recording of the stimuli. It was constructed of rubber and had been cast from a volunteer. Its ears contained miniature electret microphones.

Stimulus Generation

The warning sounds were simple "bleeps", with eight versions synthesised by computer and tailored to sound as if coming from the eight LED directions. The synthesis has been described fully in the earlier report. Of significance, the spectral compositions had been selected on the basis of judgements by independent observers, who rated the adequacy of the directional sensations produced. It had been shown in the earlier experiment that these stimuli elicited faster orientation to an illuminated LED, than a simple, non-directional warning sound. It was now required to compare these relatively unsophisticated sounds with those which incorporated the effects of the pinnae. To produce the comparison set, recordings were made through the dummy head. The same synthesised warning was employed, using only the "basic" version of the eight. This sound was played through a single loudspeaker, placed in turn in eight positions around the head. These corresponded to the eight LED locations. Thus, the head was placed in the subject's position, and warnings were

delivered from the LED directions. A random sequence of these prerecorded warnings was used in the experiment.

Subjects

12 subjects were used; students attending a psychology Summer school. None was familiar with the subject of auditory perception, nor did any have any experience of piloting an aircraft.

Method

Subjects were tested in two conditions, in one using the purely synthetic sounds and in the other the sounds recorded through the dummy head. Order of presentation was balanced across subjects. Subjects carried out the tracking task, during which one of the eight LEDs would from time to time become illuminated. Each LED was used equally often and the illumination sequence was randomised. Simultaneously with the turning on of the LED, three warning bleeps were presented over the headphones. The total duration of the warning was approximately 0.75 s and was kept short, so that it would be terminated before head-turning was initiated. This was necessary, since it was not possible to modify the prerecorded sounds in real-time, so as to allow for a changing source-head angle. The LEDs were numbered, and upon determining which was illuminated, subjects were required to type its number on the computer keyboard. The time taken from the warning onset to this response was measured.

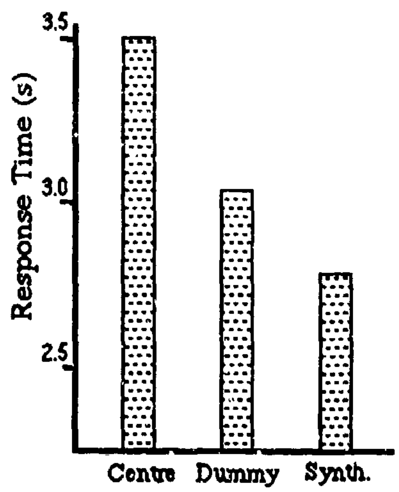

Figure 3 Mean response times following auditory warnings.

Results

Accuracy on the tracking task did not differ between the two conditions, but, contrary to what might have been expected, response times to the LEDs were significantly ($p<0.05$) faster in the purely synthetic condition. This effect is shown in Figure 3, which, for comparison, includes the mean response time to non-directional warning sounds. The data from these 'centred' warnings were obtained in the previous study.

Conclusions

It would be unsafe to deduce from the foregoing that synthetic stereo sounds will always produce a more effective response than a more natural signal. Before generalising too far, it should be noted that, although the signal recorded from the dummy head was in a sense more realistic, its true realism would only have been good for the owner of the original ears, upon whom it was moulded. However, it would seem that, by using the ratings of several judges, it is possible to produce something approaching a "generalised ear". The signal processing required to achieve this was extremely simple, and so implies that combining adequate 3-D sound with the 3-D vision of a HMD need not be a complex process.

OVERALL CONCLUSIONS

The three experiments reported have each addressed the issue of fidelity in HMDs. It is inevitable that these devices will fall short of the ideal; displays may lag slightly behind real-time, full colour may not for the time being be a practicable feature, and sounds will not be as the listener would have heard them with his own ears. There has been an additional level of infidelity in this research, in that questions concerning HMDs have been addressed with apparatus which only approximates to what the real equipment will offer. Nevertheless, we feel confident on both accounts. The simulation has been adequate to provide meaningful answers, and the results give cause for optimism about the future of HMDs, even if they preserve their imperfections.

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Attitude Maintenance Using an Off-Boresight Helmet-Mounted Virtual Display

Robert K. Osgood
Armstrong Laboratory, Human Engineering Division,
Visual Display Systems Branch
Wright-Patterson AFB, OH 45433

Eric E. Geiselman and Christopher S. Calhoun
Logicon Technical Services, Inc.
Dayton, OH 45431

SUMMARY

Helmet-mounted displays (HMDs) enable flight information to be displayed within the pilot's field-of-view, regardless of head position in the cockpit. The present research initiates the investigation of an off-boresight HMD (OBHMD), which appears when the pilot's head position is greater than 20-degrees from the aircraft's boresight. Nine subjects flew a simulated, low-level, high-speed, airborne surveillance/ reconnaissance mission, while monitoring a hostile adversary aircraft. The results indicate pilots were able to spend more time and look further off-boresight with an OBHMD than without one. In addition, missions with an OBHMD produced fewer terrain impacts. This research effort has demonstrated the promising performance benefits an OBHMD affords, as well as the need for further research to optimize OBHMD symbology.

1 INTRODUCTION

Throughout the history of avionics development, researchers have been concerned with moving flight information closer to the aviator. In this case, "closer" refers to both physical closeness and perceptual or cognitive proximity. As with the automobile, flight instruments have traditionally been on a panel in front of the pilot or operator. This configuration required the pilot to look inside the cockpit to receive necessary flight information. In the late 1950s, as aircraft became faster, and weapon systems more sophisticated, the flight environment became less forgiving of the time taken to look into the cockpit. In response to these demands, the head-up display (HUD) was developed, effectively moving flight information closer to the pilot.

The HUD optically presents a virtual image containing flight and status information, reflecting it from a transparent combiner glass to the pilot. The HUD is fixed to the top of the aircraft instrument panel so that the pilot can look through the display and windscreen in order to view the outside world. Theoretically, the pilot need only shift attention between the HUD information and natural out-the-window cues to be aware of both his surroundings and the aircraft status (situation awareness). The HUD significantly reduces the need for the pilot to look down into the cockpit, thus minimizing the associated risks of failing to see an airborne or ground threat. The HUD also enables unique information, such as the flight path marker (FPM), to be displayed. The FPM symbology displays the aircraft's automatically computed instantaneous velocity vector, irrespective of actual attitude or angle-of-attack. Essentially, the FPM represents the line or "wire" along which the aircraft is traveling, and the impact point if the aircraft were to continue on its present course. Traditional instrumentation required the pilot to scan, interpret, and integrate information from several instruments to determine the flight path.

Over the past several decades, aircraft mission environments have required pilots to fly ever faster, at lower and lower altitudes, with ever increasing sensor technology and weapon system capabilities. Under some conditions, it is now dangerous for the pilot to view anything other than the outside world and critical flight information superimposed upon it. Whereas HUDs limit information display to the forward field-of-view, helmet-mounted displays (HMD's) provide vital information within the pilot's field-of-view regardless of head position within the cockpit. The HMD is coupled to the head via a three-space tracker which monitors the helmet's position within a coordinate system of three orthogonal (x, y, and z) planes and updates the display symbology or sensor position accordingly. According to Furness (1986), graphics or symbols presented on the display may be stabilized one of four ways in virtual space: 1) head stabilized: an aim-sight reticle and cockpit-stabilized switches; 2) cockpit stabilized: cockpit displays; 3) earth stabilized: navigation waypoints and surface target locations; and 4) space stabilized: other aircraft and in-flight missiles.

Much like the HUD extended the flight envelope in modern tactical aircraft, the HMD enables the pilot to perform missions that are inherently dangerous or impossible without it. The benefits afforded by the HMD are somewhat intuitive. The HMD permits continuous display of critical flight information within the field-of-view, so that heightened situation awareness may be maintained independent of viewing area or head position. In addition, the HMD enables the use of egocentric or pilot-centered threat radar, such that symbols represent airborne or ground points of interest oriented in their actual position relative to the pilot. The pilot can then perceive and acquire beyond visual range targets in their natural orientation. With a head-coupled light-intensifying or infrared sensor, the HMD can display night vision imagery corresponding to where the pilot is looking. This, plus terrain-profiling command flight-path symbology, should

allow heightened night-flight situation awareness at lower altitudes and higher speeds than can safely be used with present HUD-only forward-looking night vision.

The basic components of HMD instrument flight symbology should indicate heading and aircraft attitude, as well as airspeed, altitude and a head-aiming reticle. The costs and benefits associated with head-coupled flight symbology are presently unknown. It is the responsibility of the HMD scientific community to evaluate the most efficient and effective ways to provide mission relevant information. Intelligent selection among candidate HMD applications must be based on empirically-derived principles of human performance, perception, and cognition. The present research initiates the investigation of a potential off-boresight display for presenting essential flight information for use in tactical mission environments.

2 METHOD

2.1 Subjects

Nine male volunteer current private pilot subjects participated in the experiment. All subjects were between the ages of 25 and 41, with a mean age of 31. All nine subjects were right-hand-dominant and had corrected or uncorrected visual acuity of 20/20 or better. Subjects' overall mean flight time was 532.22 hours, and seven out of the nine pilots were instrument-rated. The subjects did not have any military flight experience. They were paid $5.00 per hour for their participation.

2.2 Apparatus and Stimuli

The simulated visual events were displayed via a large field-of-view head-coupled binocular HMD system. This system consisted of two miniature CRTs and their associated display electronics, graphics generators, and optics, resulting in a field-of-view of 120-degrees horizontal by 60-degrees vertical, with a 40-degree subtended visual angle overlap. The CRT phosphor image was projected by an objective lens as a real image which, viewed through the eyepiece, was displayed as a virtual collimated image. The position of the helmet was measured in six axes with an electromagnetic helmet-position tracker so that the computer-generated images were cockpit, helmet, space, and world stabilized, and were constantly updated. The head tracker system was accurate to within 0.50 degrees, and maintained resolution to within 0.10 degrees.

Subjects were seated in a full-scale F-15 cockpit mock-up, and made control inputs on a center-mounted dynamic joy-stick, side-mounted F-15 throttles, and conventional rudder pedals. The simulated aircraft responded with a generic F-15 aerodynamic model. Figure 1 is a graphical representation of the HMD/simulator system. A Digital Equipment Corporation (DEC) Vax 11/785 computer collected real-time data at a rate of 10Hz.

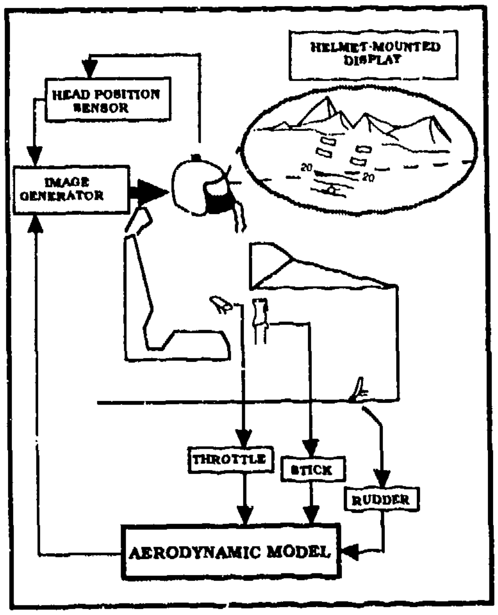

Figure 1. The Visually-Coupled Airborne Systems Simulator diagram.

Subjects flew the simulator through a virtual (world stabilized) terrain gaming area while seated in a computer-generated virtual (cockpit stabilized) cockpit presented by the HMD and generated by Silicon Graphics Iris 3130 raster graphics systems. An Evans and Sutherland stroke-generated line graphic HUD image was superimposed on the raster image and was cockpit stabilized. The HUD represented a slightly modified F-16 block 40 version symbology, and subtended 30 by 30 degrees of visual angle. The off-boresight HMD (OBHMD) symbology was also drawn in stroke graphics and appeared whenever the subject's head position exceeded 20 degrees off the aircraft's boresight. The OBHMD (see figure 2) was helmet stabilized and subtended 25 by 25 degrees of visual angle. The OBHMD symbology represents an aim-sight reticle, aircraft heading scale, digital airspeed, vertical velocity scale (in feet per second), digital/scaled altitude, and an attitude reference indicator (the attitude bars each represent +/-2.5 degrees deflection), with flight path symbol oriented to the aircraft's boresight (longitudinal axis).

2.3 Procedure

Upon entering the research facility, subjects read and signed a standard Air Force consent form. Then they were asked to read a written instruction set designed to familiarize them with the HUD symbology, HMD symbology, task scenario, and basic experimental procedure. Subjects were permitted to ask questions at any point during the instruction set, as well as during the practice and data collection sessions. Each subject participated in three sessions performed over two days. The first two sessions

were used for training (on Day one), while the third session was used for data collection (on Day two). Subjects returned to the laboratory one to eight (an average of four) days later for the data collection session.

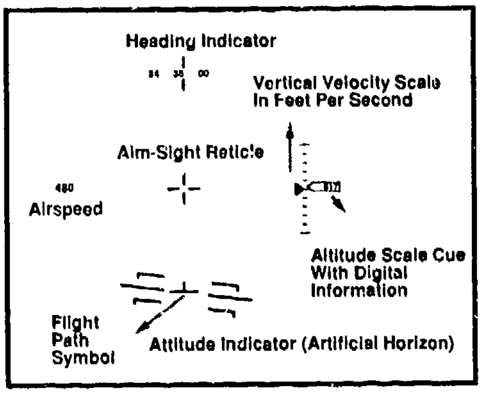

Figure 2. Labeled OBHMD symbology.

2.3.1 Training: The first training session was a "free flight" task where subjects flew the simulated aircraft through a threat-free gaming area to become familiar with the aerodynamics model, displays, and helmet apparatus. When adequate ability to maneuver the simulated aircraft was demonstrated (20-30 minutes) and an understanding of the HUD/HMD symbology was indicated, the subject moved on to the second training session. The second training session was a set of trials identical to those from the data collection session, with the exception that subjects were able to review their flight path time histories. The experimenter monitored the subject's progress and acted as an instructor throughout the training sessions. Subjects had a five minute rest halfway through the second training session.

2.3.2 Experimental Task Scenario: The task was a simulated, low-level, high-speed, airborne surveillance/reconnaissance mission. In half of the trials, subjects had a simulated HUD and OBHMD, and in the other half of trials they had only a HUD. Each trial comprised a preview mode, rest mode, run mode, and review mode (review mode for training sessions only). Subjects self-initiated each of the trials and subsequent modes within the trials by pressing the control stick trigger.

Before the start of each trial, the subject was given an overview of the terrain, heading indication and target group via a computer-generated map representing the gaming area. This was called the trial preview mode. When the mission was memorized, subjects selected trial rest mode.

In rest mode, subjects were given a reminder of the mission parameters while the proper heading, altitude and airspeed for the mission ingress was displayed. When aircraft control was activated (the control stick trigger was pulled), subjects were to proceed along a prescribed flight-path (cardinal heading) at an indicated airspeed of approximately 480 knots. Altitude was to be maintained at 400 feet above mean sea level, with terrain threats below 300 feet and surface-to-air missiles tracking above 500 feet. Although subjects were told to fly at 400 feet, there were no adverse consequences for flying below 300 feet, unless altitude went to zero (ending the trial with a terrain impact). However, if the aircraft spent more than seven consecutive seconds above 500 feet, the surface-to-air missiles (SAMs) had sufficient time to lock and fire, terminating the trial.

During trial run mode, subjects flew the simulated aircraft over the gaming area toward a group of targets in the center of the gaming area. Subjects were to continually search for visual contact with an enemy aircraft in the area. The simulated adversary aircraft (bogey) appeared between ownship's 4 and 8 o'clock position. For each trial, the bogey appeared randomly between 5 and 60 seconds after trial initiation, and continued to follow ownship for the remainder of the trial (Figure 3). The bogey randomly moved between ownship's 4, 6, and 8 o'clock position (120, 180, and -120 degrees off-boresight, respectively). When a bogey was visually acquired, the pilot was to fly his present general heading while maintaining as much visual contact with the adversary aircraft as possible (tracking task). Maintaining visual contact with the bogey required the subject to look off-boresight in excess of +/- 90 degrees. On half of the trials the bogey was programmed to fire an air-to-air (AA) missile at ownship from ownship's 4 or 8 o'clock position (hostile bogey condition). A hostile bogey fired a missile randomly between 5 and 75 seconds after the bogey appeared (Figure 3). If the subject neglected to respond to the missile, by ejecting flares and chaff, the trial was terminated. If the subject pressed the flare/chaff button while the missile was in flight, the missile was destroyed and the subject was to abort that mission and initiate a defensive 5.0 g 180 degree turn to egress. The trial would automatically end 30 seconds after the flare/chaff button was pressed. Data collection for that particular trial was terminated when ownship was struck by the missile or the flare/chaff button was pressed. The turn was intended to keep subjects motivated. For non-hostile bogey trials, the adversary would continue to trail the subject's ownship all the way to the target area. Once ownship passed over the target area, the subject was to initiate a 5.0 g 180 degree turn to egress. Trial data collection was terminated when ownship crossed over an imaginary boundary surrounding the target area. Again, the turn was intended to give the subject a difficult task to look forward to during the trial. If the subject missed the target area on the first pass, he was to turn back to the target area and attempt a second pass. On the few occasions that this situation occurred (12 trials), the subject barely missed the 4000 foot

target area diameter, so data collection ended as if no miss occurred (160 second after the trial initiation). One hundred and sixty seconds was determined to be an adequate time for ownship to cross over the target area boundary. The trial automatically ended 30 seconds after the target area boundary was crossed. At the end of a trial, subjects were told the cause of trial termination. For the training session only, trial run mode was followed by a trial review mode in which the pilot was able to review his flight path and the adversary's flight path relative to the gaming area. Prior to the data collection session, subjects were given four practice trials. Halfway through the data collection session, subjects were given a five-minute rest.

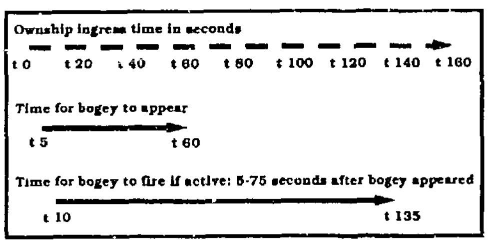

Figure 3. Bogey event time envelopes

X 4 X 2 X 9 within-subjects design. Trials were randomly presented within blocks of the 16 unique conditions formed by crossing the independent variables.

Several dependent measures were recorded and analyzed. These included altitude deviation, percent time spent off-boresight, root mean squared error (RMS) in azimuth for angular helmet position off-boresight, duration and number of exits from the altitude envelope (300 ft. and 500 ft.), reaction time to an AA missile launch, and trial terminator type (successful completion of mission, successful defense of AA missile, ground strike, AA missile strike, or SAM strike). Each trial was divided into two separate phases: the search task, before the bogey was presented (pre-bogey); and the tracking task, after the bogey was presented (post-bogey). Analyses were performed separately for each phase. Reaction time to AA missile launch and trial terminator type-dependent measures, excluding ground and SAM strikes, were unique to the post-bogey data set. In addition, for the post-bogey trial phase only, the absolute angular difference between the bogey and the subject's helmet position at the instant of an AA missile launch was recorded and analyzed.

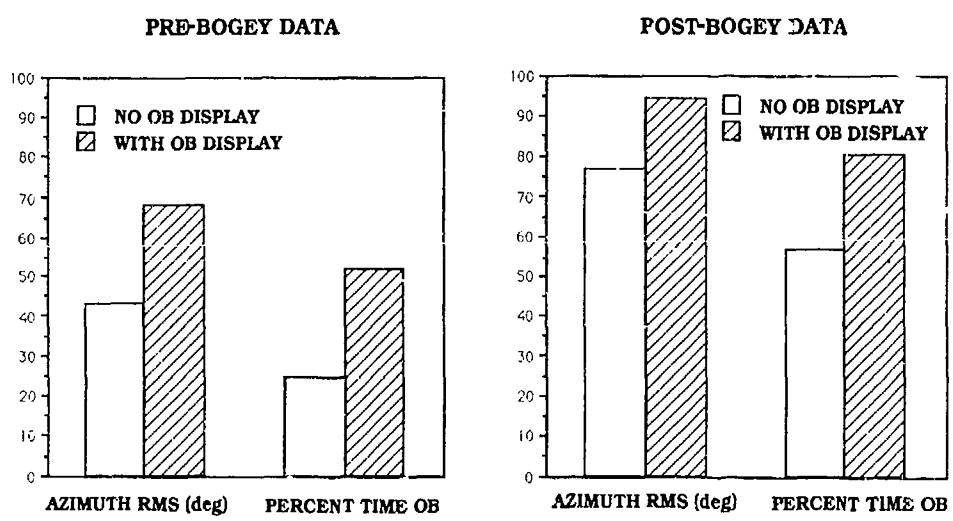

Figure 4. Pre- and post-bogey display main effects for RMS azimuth and percent time off-boresight.

2.4 Design

There were three fully-crossed independent variables included in the within-subjects design: display condition (with or without OBHMD), bogey hostility (bogey would or would not launch an AA missile), and ingress heading (north, east, south, or west). A data collection session contained 32 trials formed by crossing all levels of display condition, bogey hostility, and ingress heading, plus one replication. Two-hundred and eighty-eight total observations were collected for the 2 X 2

3 RESULTS

3.1 Pre-Bogey Phase

A full-factorial within-subjects analysis of variance (ANOVA) was performed for RMS azimuth, percent time off-boresight, and RMS altitude deviation using Display, Bogey Hostility, Heading, and Replication as main effects. The main effect of Display was significant for RMS azimuth ($F = 75.53$, $p < .0001$) and for percent time off-boresight ($F = 50.76$, $p < .0001$), accounting for 26.7 and 31.0% of the variance, respectively. (Statistical

significance for all tests were assessed using alpha = .05). There were no significant interactions. Both RMS azimuth and percent time off-boresight were larger for the OBHMD display (see Figure 4).

The frequency and duration (seconds) of altitude envelope exits, i.e., flying above 500 or below 300 ft., were used to calculate the average time flying outside the altitude envelope per exit. Time per exit was calculated for every trial and subject at the limits of the altitude envelope. To determine whether time per exit was significantly different for display, a two-tailed t-test was used. The effect of display was not significant for time per exit at 300 ft. (p = .5464) nor 500 ft. (p = .6809).

Although the ownship could not be struck by a bogey's missile in the pre-bogey phase, the trial could still end with a ground or SAM strike. There were three trials in which either of these events occurred. Two of these trials ended with an aircraft ground impact, and the third ended with a SAM strike. These events reduced the number of observations in the post-bogey phase by three (to 285).

3.2 Post-Bogey Phase

A full-factorial within-subjects ANOVA was performed for RMS azimuth, percent time off-boresight, and RMS altitude deviation, using Display, Bogey Hostility, Heading, and Replication as main effects. The main effect of Display was significant for RMS azimuth (F = 65.61, p < .0001) and percent time off-boresight (F = 59.14, p < .0001), accounting for 32.3 and 37.9% of the variance, respectively. The main effect of Bogey Hostility was significant for RMS azimuth (F = 17.28, p < .0032), percent time off-boresight (F = 28.14, p < .0007), and Altitude Deviation (F = 24.85, p < .0011), accounting for 4.2, 6.7, and 3.8% of the variance, respectively. There were no significant interactions. RMS azimuth and percent time off-boresight were larger when the OBHMD display was present (see Figure 4). In addition, RMS azimuth and percent time off-boresight were larger for the Hostile Bogey condition (see Table 1). Altitude deviation was smaller for the Hostile Bogey condition (see Table 1).

To determine whether the reaction time to deliver flares, when defending against an hostile bogey AA missile launch, was significantly different as a function of Display, a two-tailed t-test was used. The effect of Display was not significant for reaction time (p = .2864).

A full-factorial within-subjects ANOVA was performed for the absolute azimuth angle difference between the subject's head and the bogey at the time of hostile bogey fire (ABSDAZ), using Display and AA missile strikes as main effects. The main effect of Display was significant (F = 20.00, p < .0001), accounting for 25.1% of the variance. The ABSDAZ was nearly half for the OBHMD display (see Figure 5).

A Pearson Chi-square was used to determine whether the type of display affected the frequency of the trial terminator type variables. The test indicates that the successful completion of missions X^2 (1, N = 285) = 0.68, p = .410, successful defense against AA missiles X^2 (1, N = 143) = 0.03, p = .868, AA missile strikes X^2 (1, N=143) = 0.07, p = .799, and SAM missile strikes X^2 (1, N = 285) = 0.08, p = .780 do not depend upon the type of display used. However, ground strikes did depend on display type. There were zero ground strikes (out of 143 trials) when aided with the OBHMD, and five ground strikes when the OBHMD was not present (out of 142 trials). This effect was statistically significant X^2 (1, N = 285) = 5.13, p = .024.

4 DISCUSSION

As previously mentioned, each trial was divided into two phases, pre- and post-bogey. Each phase represents a different task. The pre-bogey phase involves a search-type task, i.e., the subject is continually searching for the arrival of the bogey and is not concerned with hostile AA missile attack. The post-bogey phase represents a tracking-type task, i.e., the subject is aware of the bogey's location, but must maintain visual contact in the case of a hostile AA missile attack.

Clearly, subjects looked off-boresight for a longer duration and maintained a larger off-boresight angular azimuth displacement while using an OBHMD. This

Metric	Bogey Hostility: Non Hostile	Hostile
RMS azimuth (degrees)	82.3	88.3
Time off-boresight (%)	63.8	73.3
Altitude deviation (feet)	70.1	55.6

Table 1. Means for significant effect of Bogey Hostility in Post-Bogey

To determine whether time per exit was significantly different for Display, a two-tailed t-test was used. The effect of Display was not significant for time per exit at 300 ft. (p = .6896) nor 500 ft. (p = .6762).

occurred for both the pre-bogey and post-bogey phases. The performance differences between the search and tracking tasks are evident in Figure 4, where the means for head azimuth angle and percent time off boresight for the

pre-bogey data are less than those for the post-bogey data. This may be due to the subjects moving from the 4 to 8 o'clock position, and back again, more frequently. Another interesting effect was Bogey Hostility. In the post-bogey phase, a non-hostile bogey produced a smaller RMS azimuth, less percent time off-boresight, and more altitude deviation. These effects appear to be attributable to the length of the trial. That is, trial length was longer when the bogey was non-hostile, thus altitude deviations had more time to accumulate. The lack of this effect in the pre-bogey phase lends support to this interpretation. believed that this is sufficient time for the subject to look away from the bogey (check the HUD or look for the target area) and look back at the bogey in time to see the missile in flight. On the other hand, it was possible that the subject could have, after looking forward, returned his head to the last known location of the bogey, but by that time the bogey had crossed behind to a new position. This would render him vulnerable to a missile strike. This same scenario could be applied to the trials with the OBHMD. When the subject looked on-boresight to check ownship forward progress, he might

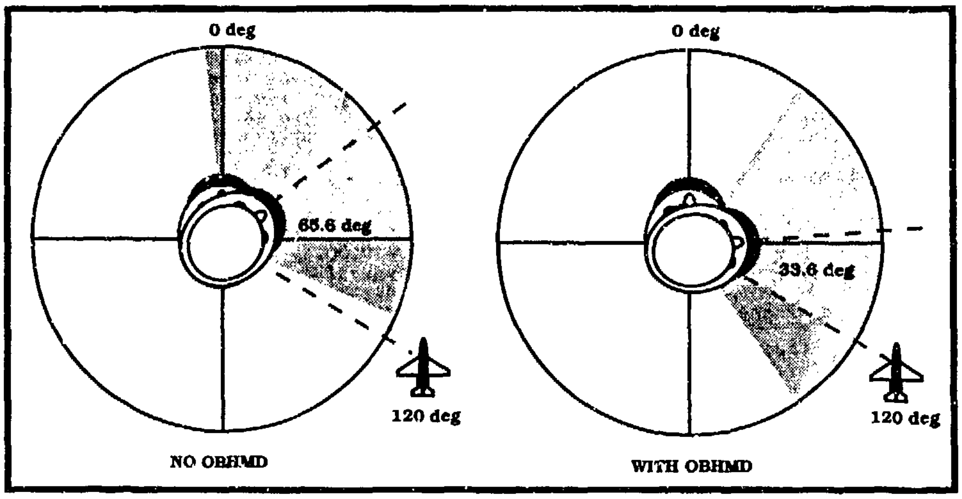

Figure 5. Head azimuth relative to the bogey at instant of AA missile launch.

An OBHMD does not affect the reaction time to deliver flares when defending against a hostile bogey AA missile launch. However, the ABSDAZ indicates that a reaction time difference should indeed be evident. Figure 5 suggests that the subjects were more likely to be looking at the bogey when it launched if they had the aid of the OBHMD. It is possible that, since the subject saw the bogey fire, there was no sense of urgency to press the chaff button. If the subject witnessed the launch, he had a good idea of how long the flight time of the missile would be, and that there was no immediate danger. Exercising this state of relaxation, the subject did not react to the missile with great speed. Without the OBHMD, the subject spotted the missile in flight and, because he did not see the launch, it was imperative to react as fast as possible. If the subject did not see the missile, he may not have had a good feel for the missile time of flight, thus it was urgent that he react to the missile as soon as possible.

The fact that there were no differences between the displays, in terms of number of times hit by an AA missile, may be directly attributable to the flight time of the missile. For the present experiment, the average flight time of the missile from launch to the time it hit ownship was about six seconds. It is not have been able to get to the correct location in time to see the missile in flight. In this case it was a matter of looking at the wrong place at the wrong time.

The findings of the present study suggest that the off-boresight attitude display enhanced the pilot's search capability, tracking performance and survivability. With this display, both the duration of off-boresight visual scanning and the angle with which the pilot was able to scan the aerial environment for bogey aircraft was increased. In addition, the number of times ownship experienced a ground strike with the off-boresight display was zero.

The findings of the present study favor the use of an OBHMD but future efforts should be made to increase the realism of the task. The authors recommend future incorporation of a variable-terrain-elevation gaming area in which the pilots would be required to maintain a constant separation from the surface. Additionally, the expansion of the bogey aerodynamic model to include elevation deviation would permit a much more difficult task and greater element of surprise. It is also reasonable to surmise that although off-boresight attitude display symbology enhanced mission success, the symbol set has yet to be optimized.

5 ACKNOWLEDGEMENTS

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METHODOLOGIE DE CONCEPTION D'UN VISUEL DE CASQUE: LES ASPECTS ERGONOMIQUES.

J.M. Kraus, P. Lacroux, A. Leger
Division Visualisation Interface
SEXTANT Avionique
33166 St Médard En Jalles Cedex, Fr

Résumé: Sur un plan purement visionique, la conception d'un visuel de casque ne présente que relativement peu de différences avec un dispositif de visualisation plus classique, comme le viseur tête-haute. Pour l'ingénieur, l'une des difficultés majeures rencontrées dans la conception d'un système monté sur la tête réside dans le fait que la structure porteuse est loin d'être aussi bien définie que les supports habituels. La diversité des "spécifications" anatomiques et fonctionnelles de la tête du pilote constitue donc la source de contraintes ergonomiques qui doivent impérativement être prises en compte.

La première partie de cette étude est constituée par une démarche d'identification précise des contraintes rencontrées: contraintes anthropométriques, biomécaniques et de sécurité, de confort et de manipulation, d'environnement.

A partir des données issues de la recherche amont, la Conception Assistée par Ordinateur (CAO) et la réalisation simultanée de maquettes d'encombrement et ergonomiques permet une approche globale de ces différents problèmes. La deuxième partie de l'étude expose les aspects essentiels des principes méthodologiques utilisés.

En conclusion, la réflexion menée à propos de la démarche de développement d'un visuel de casque fait apparaître la nécessité d'une intégration précoce des aspects visioniques et de l'ergonomie du support. Il s'agit là d'un atout majeur et indispensable pour aboutir à la réalisation d'un matériel satisfaisant à la fois aux nécessités imposées par le système d'armes et les utilisateurs.

1. INTRODUCTION

Sur tous les avions d'armes modernes et sur beaucoup d'hélicoptères, la conduite de la plate-forme et du système d'armes fait, à l'heure actuelle, largement appel au viseur tête haute. Les limitations de ce type de visualisation, aussi bien pour la désignation d'objectifs que pour la navigation jour-nuit, sont aujourd'hui largement reconnues (4). On peut donc définir le viseur de casque comme un viseur tête haute mobile, comblant les lacunes du viseur classique, intégré au casque du pilote et destiné à faciliter la conduite de la plate-forme et du système d'armes.

D'une manière générale, cet équipement comprend une unité électronique montée en soute, un dispositif de mesure de la ligne de visée et un équipement de tête. L'équipement de tête assure la protection physiologique du pilote et constitue le support du dispositif de visualisation. Le tableau I résume les principaux composants d'un visuel de casque.

Si quelques viseurs ou visuels de casque sont déjà en service opérationnel sur différents porteurs (AH-64 "Apache"par exemple), cet équipement ne deviendra véritablement universel qu'à partir de la seconde moitié des années 90. La société SEXTANT Avionique, pour sa part, est d'ores et déjà engagée en association avec VDO-L, dans le développement d'un visuel de casque pour le programme d'hélicoptère Franco-Allemand "Tigre" (1) et propose, en association avec Intertechnique, un visuel de casque dans le cadre du programme "Rafale".

Pour mener à bien ce type de projets, les équipementiers sont confrontés au même problème: prendre en compte les multiples contraintes ergonomiques liées au support du viseur, la tête du pilote, dans la conception du viseur de casque. En effet, la réussite ne se jugera pas seulement sur la tenue des spécifications techniques habituelles des équipements de visualisation (champ, contraste, qualité d'image,...), mais bien principalement sur l'acceptation ou non du produit par les pilotes. Cette acceptation sera garante de l'efficacité opérationnelle attendue, dont la démonstration a pu être faite soit par des essais en simulateur (2), soit par des essais en vol.

La conception est rendue d'autant plus difficile qu'aux contraintes ergonomiques d'origine purement humaines, anthropométrie, biomécanique, confort, manipulation, il convient d'ajouter les contraintes opérationnelles et celles découlant de l'intégration sur le porteur.

2. IDENTIFICATION DES FONCTIONS ET CONTRAINTES

L'identification des fonctions que doit assurer l'équipement de tête et des différentes contraintes qui en découlent comporte des particularités propres au type de porteur. Cependant, un certain nombre de points communs peuvent être dégagés avec une valeur relativement universelle (5).

2.1. Fonctions de l'équipement de tête

L'évolution actuelle tend à assigner aux porteurs futurs des missions de plus en plus complexes à effectuer dans des conditions d'environnement de plus en plus sévères (vol de nuit, ambiance NBC, ...). Pour effectuer au mieux ces missions et répondre aux besoins futurs il est nécessaire de développer un équipement de tête intégrant les fonctions de

présentation d'informations visuelles, d'asservissement de capteurs et d'armements, de communication et de protection physiologique.

2.1.1. Présentation d'informations visuelles

Le visuel de casque fournit au pilote une image collimatée à l'infini et superposée au paysage. Cette image peut provenir d'une caméra thermique (type FLIR), d'un système de cartographie numérique, d'un radar ou d'intensificateurs de lumière de troisième génération intégrés au casque. Une symbologie synthétique d'aide au pilotage, à la navigation et au tir peut être superposée à ces images. Il s'agit donc d'assurer les fonctions d'un véritable viseur tête haute multimode, avec en supplément l'intégration des intensificateurs de lumière.

Selon la nature des informations, on s'oriente vers des présentations monoculaires avec des champs de l'ordre de 15 à 20 degrés (symbologie pour avions de combat), ou binoculaires, avec un champ d'au moins 40 degrés, et si possible avec un recouvrement total entre chaque image (hélicoptère en vol tactique de nuit, photo 1).

2.1.2. Asservissement capteurs et armements

A l'équipement de tête est associé un système de détection de position et d'orientation permettant de connaître la position du casque dans l'espace, l'orientation de la ligne de visée ainsi que l'information de roulis de la tête du porteur du casque. Ce système permet d'asservir sur les mouvements de la tête, soit des capteurs optroniques, le pilote gardant ainsi une image vidéo correspondant à l'image réelle quelle que soit la direction de sa ligne de visée, soit des systèmes d'armes. Dans les solutions techniques habituellement retenues, l'équipement de tête intègre un capteur électromagnétique miniature.

2.1.3. Communication

L'information auditive revêt une importance fondamentale dans les communications entre les membres d'un même équipage ou avec l'extérieur. Cette fonction doit, bien sûr, être intégrée à l'équipement de tête et garantir la compatibilité avec les systèmes de commande et de synthèse vocale.

Il faut noter qu'à côté ou en association avec les liaisons auditives classiques, on demande également au visuel de casque de permettre la liaison selon un mode visuel ("regarde où je vise") entre membres d'un même équipage ou éventuellement entre aéronefs.

2.1.4. Protection physiologique

L'équipement visuel de casque doit assurer l'ensemble des protections physiologiques habituellement apportées par l'équipement de tête classique du pilote. Ce sont essentiellement la protection contre les chocs mécaniques et les perforations, l'éblouissement solaire ou laser et le flash nucléaire, le bruit. Il doit également être compatible avec les systèmes d'oxygénation et de protection contre les accélérations (surpression respiratoire) et assurer une protection efficace lors de l'éjection. Enfin il doit être utilisable en ambiance contaminée et donc intégrer ou pouvoir être juxtaposé avec un équipement NBC.

2.2. Contraintes ergonomiques et opérationnelles

L'existence de ces contraintes constitue une source de difficultés non-négligeables sur le plan technique. Il faut aussi reconnaître que la technologie des viseurs de casque constitue en elle-même une problématique relativement nouvelle. L'expérience acquise dans la réalisation de divers équipements prototypes destinés aux études en simulateur et aux essais en vol a amplement démontré l'impérieuse nécessité de prendre en compte très tôt ces contraintes dans la conception d'un équipement véritablement opérationnel.

2.2.1. Contraintes humaines

L'identification détaillée de ces contraintes s'appuie sur les études amont menées, sous l'égide des services Officiels Français, dans divers laboratoires spécialisés dans l'étude des facteurs humains, comme le Laboratoire d'Anthropologie Appliquée (LAA), le Laboratoire de Médecine Aérospatiale du Centre d'Essais en Vol (CEV/LAMAS), l'INRETS de Lyon.

2.2.1.1. Contraintes anthropométriques

Il existe une grande variabililité dans la morphologie de la tête humaine. Pour pouvoir être utilisé efficacement l'équipement doit être le plus parfaitement possible ajusté à la morphologie du pilote. L'identification de cette contrainte fait appel à des études anthropométriques. De nombreuses bases de données existent, certaines s'intéressent en particulier à la morphologie de la tête et de la face (3). Ces bases de données permettent de définir, dans les repères classiques utilisés en anthropométrie, les principales données nécessaires à la conception des équipements, emplacement des yeux, forme et dimensions de la tête, emplacement et morphologie des pavillons auditifs.

2.2.1.2. Contraintes biomécaniques

Le cou du pilote, en particulier du pilote de chasse, est systématiquement l'objet d'agressions liées à l'environnement du vol (accélérations , vibrations). Les lésions qui peuvent résulter de ces facteurs d'agressions ont été amplement documentées (10). De plus, des circonstances exceptionnelles, comme les éjections ou les atterrissages forcés, sont également susceptibles d'entraîner des blessures graves.

La masse additionnelle représentée par l'équipement de tête, si elle est excessive, va directement aggraver cette situation. Les études de biomécanique (8, 9) montrent, qu'outre le problème de l'accroissement du poids supporté par le cou, l'éventuel déplacement du centre de gravité de la tête équipée et les caractéristiques d'inertie de l'équipement peuvent également poser un problème dans le domaine de la sécurité. Il faut également être bien

conscient que les considérations statiques prenant uniquement en compte les couples et forces maximales en cause sont largement insuffisantes pour résoudre ce problème. La réponse biomécanique de la tête à des forces appliquées de l'extérieur est en effet très dépendante du domaine fréquentiel des stimulations. Seules les approches fondées sur l'utilisation de stimulations dynamiques peuvent espérer rendre compte des limites de tolérance du cou, en particulier vis à vis des accélérations + Gz.

2.2.1.3. Confort

Un équipement, quel qu'il soit, ne peut prétendre être réellement opérationnel que s'il apporte à l'utilisateur un confort suffisant. En fait, il ne faut pas oublier que ce confort est également un gage important d'efficacité. Pour ce qui concerne l'équipement de tête et plus particulièrement le viseur de casque, différents points sont à prendre en considération.

C'est en premier lieu le problème du confort thermique. La conception de l'équipement doit comporter les mesures passives ou actives visant à rendre minimale la charge thermique au niveau de la tête. La liberté de mouvement de la tête constitue également un point important qui participe à l'efficacité de l'équipement. La personnalisation de l'équipement, pour sa part, n'est pas seulement un élément de confort. Il est bien connu qu'un équipement trop ajusté peut, après quelque temps de port, se révéler totalement insupportable en raison des phénomènes douloureux qu'il entraîne. D'un autre côté, afin de minimiser les réglages et d'assurer une bonne stabilité du casque sur la tête, il convient d'avoir un revêtement interne relativement ferme et adapté à la forme du crâne. Associé à une contention efficace, la personnalisation de l'équipement représente donc une nécessité pour les équipements futurs. La fatigue résultant du port de l'équipement est également une source de préoccupation importante pour le maintien de l'efficacité du pilote. On rejoint ici les considérations biomécaniques de masse de centre de gravité et d'inertie qui ont été évoquées pour les aspects de sécurité. En fait les études biomécaniques menées sur ces différents aspects, sécurité, fatigue et mobilité, montrent que des compromis seront nécessaires pour assurer l'efficacité opérationnelle.

2.2.2. Contraintes opérationnelles et d'intégration au porteur

Les conditions de vol impliquent l'utilisation de visières comme moyen de protection oculaire. La manipulation des visières doit pouvoir être effectuée facilement en vol, même dans le cas le plus défavorable où deux visières sont utilisées. En particulier le pilote doit pouvoir accéder facilement à son visage en cas de besoin. De la même façon, les réglages interpupillaires de systèmes de visualisation binoculaires doivent être facilement accessibles même avec des gants.

Les contraintes d'intégration au porteur font appel à une collaboration étroite avec les avionneurs. Elles comportent les problèmes de compatibilité spectrale (éclairage cabine pour la partie visualisation), le cheminement des câbles et l'encombrement de l'équipement de tête, enfin les problèmes liés à l'implantation de l'émetteur électromagnétique de la détection de position de tête.

3. METHODOLOGIE DE CONCEPTION

Les principes généraux qui, sur le plan ergonomique, guident la conception d'un équipement aussi complexe qu'un viseur de casque reposent sur l'association de trois techniques fondamentales. C'est d'une part l'utilisation de modèles de simulation, issus pour la plupart des études amont, qui permettent de fixer des valeurs limites et d'optimiser les paramètres importants, comme le centre de gravité ou l'inertie des équipements. C'est aussi, compte tenu de la complexité mécanique des systèmes, le recours à la conception assistée par ordinateur qui rend possible la maîtrise en temps réel des diverses caractéristiques de l'équipement. C'est enfin l'utilisation systématique du maquettage, aussi bien maquettes ergonomiques que maquettes de cabine destinées à vérifier la compatibilité avec l'environnement. Cette méthodologie générale sera illustrée par quelques exemples précis.

3.1. Prise en compte des aspects biomécaniques

La prise en compte des contraintes biomécaniques amenées par l'utilisation d'un viseur de casque constitue une partie importante de la démarche ergonomique qui doit être entreprise dans le cadre de la conception de l'équipement. Les aspects de sécurité, de confort et de mobilité doivent pouvoir être considérés d'une manière globale. D'autres aspects touchant les problèmes de sécurité seront également abordés à titre d'exemple.

3.1.1. Masse - Inertie - Centre de gravité

Les problèmes liés à la masse, aux caractéristiques d'inertie et au déplacement du centre d'inertie de la tête équipée, bénéficient de l'utilisation de plusieurs techniques, comme les modèles anthropométriques, la conception assistée par ordinateur (CAO), les modèles mathématiques dynamiques. La réalisation de maquette ergonomiques complète cette démarche.

Couplée avec l'utilisation d'un modèle anthropométrique de tête humaine conçu par le LAA, la CAO constitue un outil indispensable qui seul autorise d'une manière satisfaisante la représentation dans l'espace d'équipements complexes complets. Il est également possible de calculer avec une grande précision les caractéristiques globales de l'ensemble mécanique monté sur la tête (masse, inertie et centre de gravité) et de référencer ces données dans le repère anatomique de la tête. L'obtention de ces caractéristiques permet alors de tirer parti des informations qui peuvent être fournies par les modèles mathématiques dynamiques.

Les modèles mathématiques de simulation de la réponse de la tête apportent une aide précieuse dans ce domaine. Ils permettent en effet de prendre en compte les aspects dynamiques des stimulations rencontrées en aéronautique, tout particulièrement pour ce qui concerne les aspects de sécurité, (éjection, choc à l'ouverture du parachute,

crash,..). On peut ainsi calculer, en fonction de la masse de l'équipement additionnel et de ses caractéristiques d'inertie et de l'emplacement de son centre de gravité, les contraintes mécaniques résultant d'une stimulation dynamique appliquée au niveau du système tête-cou. La figure 1 donne un exemple de l'effet d'une stimulation du type Aces II (8) appliquée directement au niveau de la charnière cervico-dorsale (stimulation du type choc à l'ouverture de parachute). L'indice biomécanique étudié ici est l'énergie , résultant de la rotation de la tête autour de l'axe y, transmise au niveau de la première vertèbre dorsale. Cet indice a été avancé comme potentiellement intéressant pour la représentation des risques de lésion encourus (7).

Pour ce qui concerne les problèmes de fatigue et de tolérance aux accélérations, les problèmes rencontrés sont plus complexes et loin d'être encore totalement résolus. Il pourrait en effet exister des contradictions entre les caractéristiques requises pour une sécurité optimale, une minimisation de la fatigue et une conservation de la mobilité en particulier sous facteur de charge (6). Dans ce domaine, il est particulièrement illusoire de considérer uniquement des conditions statiques et une position neutre de la tête. C'est là souligner tout l'intérêt que représente l'utilisation de maquettes ergonomiques, éventuellement utilisées dans des environnements dynamiques (centrifugeuse, plate-forme vibrante).

Les maquettes ergonomiques permettent par ailleurs de tester le fonctionnement des différents composants mécaniques mobiles des équipements. Présentées à des pilotes et aux spécialistes des facteurs humains elles constituent une étape fondamentale de la démarche ergonomique utilisée dans le développement d'un viseur.

3.1.2. Caractéristiques structurelles et aérodynamiques

La modélisation des caractéristiques structurelles et aérodynamiques de la coque du casque supportant le viseur constitue également un point intéressant pour les aspects ergonomiques de la conception.

La résistance structurelle est un élément important de la protection de la tête lors des chocs. D'autre part, les déformations et contraintes sous l'effet de forces appliquées de l'extérieur (accélérations, chocs, actions de l'utilisateur) méritent d'être analysées pour optimiser l'implantation des différents éléments optiques et mécaniques constituant le viseur. L'effet de souffle subi par le pilote lors de l'éjection d'un avion de combat amène souvent la perte du casque et, éventuellement, l'apparition de lésions du système tête-cou. L'étude des caractéristiques aérodynamiques de l'équipement de tête constitue donc un point intéressant.

Les techniques de simulation utilisant le maillage par éléments finis permettent de répondre à ce type de considération aussi bien pour les contraintes mécaniques qu'aérodynamiques. Elles constituent donc un apport intéressant dans ces deux domaines.

3.2. Réalisation de l'intégration au porteur

L'intégration de l'équipement au porteur, outre les nombreux aspects purement techniques qu'elle comporte, présente également certains aspects ergonomiques. Ce sont essentiellement les problèmes de cinématique et d'identification des masques visuels. Comme pour les aspects biomécaniques, la méthodologie de conception repose sur l'utilisation de techniques de simulation et de maquettage (maquettes ergonomiques, d'encombrement de l'équipement de tête, maquettes de cockpit).

La simulation au moyen de modèles mathématiques anthropométriques de la cinématique de la tête du pilote équipé du casque lors de divers types de mouvement permet de vérifier la non-interférence de l'équipement avec la structure du porteur. Ces études sont généralement complétées par des maquettage en grandeur réelle qui permettent de vérifier, pour un échantillon de pilotes, les résultats obtenus lors des simulations. Le travail sur maquette constitue également un moyen commode pour identifier précisément les éventuels masques visuels et y remédier.

4. CONCLUSIONS

La prise en compte des facteurs ergonomiques dans la conception des visuels de casque constitue un élément fondamental d'une démarche visant à assurer l'efficacité opérationnelle du produit final. Différents points méritent d'être soulignés.

La démarche ergonomique doit être réalisée dès les premiers stades de la conception de l'équipement, simultanément avec le développement du concept retenu pour la visionique. Elle nécessite une synergie de tout les instants entre les différentes parties prenantes, équipementier, avionneur, utilisateurs, laboratoires de recherche. Elle implique également une grande synergie des métiers dans la réalisation même de l'équipement, électronique, optique , mécanique, facteurs humains. Ces aspects multidisciplinaires constituent en fait l'essence même de l'ergonomie.

Enfin, la mise en oeuvre de méthodes de conception évoluées, comme l'utilisation de modèles mathématiques de simulation, de la CAO et des techniques de maquettage apparaît également comme un élément indispensable de cette démarche.

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__Figure 1 :__ Matrice des valeurs d'énergie de rotation au niveau de D1 (en Joules), calculées par un modèle mathématique du système tête-cou, en fonction de la masse, de l'inertie et de l'emplacement du centre de gravité de l'équipement par rapport au centre de gravité de la tête nue. Xa est la position du centre de gravité sur l'axe X (positif vers l'avant), Za est la position sur l'axe Z (positif vers le haut). La masse additionnelle concernée est de 1,5 kg, pour une inertie de 0,5 kg.m2. Les valeurs les plus faibles obtenues pour chaque pas de calcul en X ont été encadrées.

Ma = 1.5kg Ia = 0.05kg.m2

Xa =

	-30mm	-21.1mm	-12.2mm	-3.3mm	5.6mm	14.5mm	23.4mm	32.3mm	41.1mm	50mm
Za = 70mm	200,62	198,73	196,83	194,93	193,05	191,18	189,34	181,52	185,72	183,94
Za = 60mm	198,57	196,78	194,98	193,18	191,37	189,58	187,80	186,04	184,29	182,56
Za = 50mm	197,03	195,25	193,46	191,68	189,90	188,13	186,38	184,63	182,91	181,19
Za = 40mm	195,33	193,58	191,83	190,09	188,36	186,63	184,91	183,21	181,51	179,84
Za = 30mm	176,44	178,07	179,73	181,41	183,10	184,80	186,51	188,23	189,97	191,70
Za = 20mm	177,68	179,34	181,03	182,74	184,47	186,21	187,96	189,72	191,49	193,26
Za = 10mm	178,98	180,64	182,34	184,07	185,81	187,56	189,34	191,12	192,91	194,72
Za = 0mm	180,41	182,12	183,86	185,60	187,42	189,23	191,07	192,92	194,79	196,68
Za = -10mm	182,14	183,85	185,60	187,39	189,19	191,02	192,88	194,75	196,64	198,53
Za = -20mm	183,99	185,68	187,41	189,19	190,99	192,81	194,66	196,53	198,39	200,27

EQUIPEMENTS	*SOUS-ENSEMBLES*
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EN CABINE	EMETTEUR MAGNETIQUE
EN SOUTE	CALCUL LIGNE DE VITESSE, GENERATION SYMBOLES, INTERFACE SNA

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Tableau I : Composition d'un visuel de casque

Photo I : Visuel de casque binoculaire - bisenseur

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